THE PERFORMANCE AND ERRORS OF COLLEGE OF SCIENCE STUDENTS IN ENGINEERING IN FIRST AND SECOND YEAR APPLIED MATHEMATICS AT THE UNIVERSITY OF THE WITWATERSRAND

Anne Rosemary Tyldesley Gray

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DECLARATION

I declare that this research report is my own unaided work. It is being submitted for the Degree of Master of Science in Science Education in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other university.

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(Signature of candidate)

This______________ day of _______________, ________

Abstract

This research report is an ex post facto study of the students from the General College of Science in the University of the Witwatersrand who chose to do Engineering Sciences in the College and who then progressed to second year Engineering in the Chemical, Civil, Metallurgical and Mining Engineering branches.

The College students are compared to selected groups of main stream students (who entered the Engineering Faculty via the normal route) in the following areas : Teaching methods used in the College compared to teaching methods used in the main stream; pass rates and distribution of the final marks for each course; marks obtained for individual questions on examination papers; and the types of answers given to examination questions.

The results show that although the College students start their university careers from a more disadvantaged position than the main stream students do, their performance has become equivalent to that of the main stream students at the end of the period studied.

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Contents

List of Tables

Chapter 1 : Introduction

1.1 Background to the Establishment of the College of Science.

Many South African secondary schools do not provide the scientific background required for success in university science and engineering faculties. Before 1990, when the College of Science was established at the University of the Witwatersrand, the situation was particularly bad in schools that catered for black pupils. The black schools in particular offered a limited number of science courses, usually taught by teachers without formal qualifications or adequate facilities. Few schools offered higher grade mathematics or physical science.

Since the 1970s, the Science Faculty and the Engineering Faculty at the University of the Witwatersrand have had several different schemes for enhancing the ability of students from disadvantaged backgrounds. In the Science Faculty there was a four-year curriculum which allowed science students two years to complete their first-year courses and the Academic Support Programme (ASP) which provided tutors who ran extra classes for these disadvantaged students. The Engineering Faculty had the Engineering Support Programme and the Wits Integrated Studies Programme for Engineers (WISPE) which allowed students to take three years to complete the first two academic years.

The College of Science was established in 1990 to extend and consolidate the successful aspects of the existing programmes addressing the needs of promising students systematically disadvantaged by the educational system in place at the secondary level.

The College provides access to the University to students who wish to study for a Bachelor of Science, (BSc), degree and, until 1998, provided access to a Bachelor of Engineering Science, BSc(Eng), degree to matriculants with matric symbols in mathematics and physical science which are too low for automatic entry into the faculties of Science or Engineering (For an explanation of automatic entry conditions for the Engineering Faculty, see Appendix 1)

The College of Science accepted students from the Engineering Faculty for the first time in 1992, but in 1998 the Faculty decided to develop their own bridging programme and the last cohort of Engineering students completed their College courses at the end of 1999.

Since 1990, the situation has not improved in secondary schools, as evidenced by the matriculation pass rates, so the College still provides an important access point to promising students who need a couple of years at university as the real and best test of whether they can succeed at university.

1.2 The College of Science.

In other parts of the world, for example in the United States, the word 'college' is used to describe the undergraduate programme of a university, and that is how the University of the Witwatersrand uses the term. It is NOT used as another word for 'high school' or a College of Education for teacher training.

The College of Science admitted its first students in 1991. It is an integrated two-year programme for students wishing to study science (or engineering from 1992 to 1998) at the University of the Witwatersrand. Its students are University students able to make use of all the University's facilities and are not separated from the University in any way.

The College offers a challenging and demanding curriculum to help students overcome the effects of poor teaching and inadequate facilities that characterise most South African secondary schools.

The College is an integral part of the Faculty of Science on the campus of the University of the Witwatersrand , and College students are University students registered in the Faculty of Science (or the Faculty of Engineering from 1992 to 1999). College students have the same lecture rooms and laboratories, and many of the same lecturers, as other students. University accommodation for College students on campus is also allocated in the same way as to all University students. Some students live at home and commute to Wits, but about 60% of College students live in University accommodation.

The College staff is composed of a core administrative group, and lecturers who are housed in their academic departments. Most College lecturers also lecture in their own departments to main stream students.

Acceptance into the College can lead to a BSc in a wide range of subjects, or for those who entered through the Faculty of Engineering, to a BSc(Eng) in any branch.

This Research Report focuses on a group of students that registered with the College of Science with the intention of proceeding to the main stream Engineering courses offered at the University of the Witwatersrand.

1.3 Admission Requirements for Prospective Engineering Students in the College of Science.

The College (and the University) requires that all applicants must have a certain proficiency in English. For South African students this normally means that a prospective student must have passed matriculation English at the Higher Grade (1st or 2nd Language).

Applicants were considered for admission to the College via the Engineering Faculty if they fell into one of the following categories :

1. Those with matriculation exemption with at least an E symbol in Higher Grade Mathematics and Physical Science. and with a matric rating of 16 or more, but less than the required points for automatic entry for their chosen branch of engineering. The table showing the requirements for automatic entry into the Engineering Faculty is in Appendix 1.

2. Those who did have the required points, but who felt that their preparation was inadequate, (particularly in Mathematics, Physical Science or English) to enter the standard four-year curriculum were also encouraged to seek admission via the College of Science.

3. Those with standard grade Mathematics and/or Physical Science could apply for a BSc in the Faculty of Science and write the Science selection tests. If accepted for the College of Science such students could apply to the Engineering Faculty at the end of their first year in the College provided that they had taken Engineering Sciences as their optional course.

4. Mature age applicants were also considered for admission provided they were able to obtain a mature age exemption certificate from the Matriculation Board.

All applicants who wanted to be considered for admission to the College were required to write the Science selection tests. Performance in the College of Science selection tests enabled the Faculty to guide an applicant on whether he or she was sufficiently prepared for the standard four-year curriculum or should rather take an extended curriculum through the College of Science, or was completely unsuited for university admission.

The selection tests were developed over a number of years by staff of the College when they were lecturing in their respective departments, in an attempt to identify candidates for the four-year curriculum and the ASP classes. The College acknowledges that their selection tests are not infallible, and that some students who are admitted will not succeed. The tests consist of multiple choice questions and are written in one morning.

The tests are :
- Matric level mathematics and physical science - testing basic principles that the students should know,
- a science aptitude test,
- a spatial ability test and
- a logical sequencing test.

The students also fill in an autobiographical questionnaire.

1.4 Courses Taken by Engineering Students in the College

In their first year of study all students in the College study Physical Sciences IA and Mathematical Sciences IA. The science students also choose one additional course. This may be Biological Sciences IA, Earth Sciences IA, or Engineering Sciences IA. The engineering students had to take the Engineering Sciences course. The fixed core of courses gives a broad education in science, and also contains problem solving skills, cognisance of scientific language and reasoning, and study and learning skills in all subject areas.

In the second year of study, Engineering students studied Physical Sciences IB, Mathematical Sciences IB and Engineering Sciences IB.

1.4.1 Physical Sciences

This course was a joint course in Physics and Chemistry. The physics part of the course covered the same content as the physics course taken by the mainstream students. The chemistry was an extension of chemistry that should have been done at secondary school. The content of the Physical Sciences course can be found in Appendix 2.

1.4.2 Mathematical Sciences

This course consisted of algebra and calculus that covered the same content as the mathematics course taken by the main stream students. The content of the Mathematical Sciences course can be found in Appendix 2.

1.4.3 Engineering Sciences (First Year)

The course was called MECN122 Engineering Sciences IA and consisted of :

- **Professional Studies**

  Academic skills: study; listening; reading; notetaking; scientific text types; oral presentation. Scientific writing: clarity; precision and logic; register; describing a process; developing an argument.

- **Graphics**

  Engineering drawing standards; freehand sketching; geometrical construction. Orthographic; oblique; isometric and auxiliary constructions; fundamental spatial relations; intersections; sectioning; developments; assembly drawings.

- **Mechanics**

  In the **first semester of 1993**, (February to June), there were a series of problem solving skills developing tutorials, followed by Newton's Law of Universal Gravitation, and modules covering kinematical behaviour, vectors, empirical forces, friction, use of free body diagrams, constraint forces; differentiation and integration of simple functions. In the **second semester**, (July to October), the topics covered were Kinematics - motion in a straight line; Newton's Laws of Motion; Motion in a two-dimensional plane; Work, power and energy; Impulses; Conservation of momentum; Motion in a circle.

From the **beginning of 1994, the first semester** was used to give students a computing course (for two periods per week) and a mechanics laboratory, visits to engineering sites and lectures introducing engineering topics in the remaining two periods per week. The students were split into three groups which took turns to do one of the three activities each week. The mechanics laboratory covered specific topics in mechanics and made use of a set of equipment that enabled students to build structures that illustrated the topic, for example single and double pullies.

From 1994, the following topics were covered in the **second semester**: Modules covering kinematical behaviour, vectors, empirical forces, friction, use of free body diagrams, constraint forces; Newton's Law of Universal Gravitation; Forces at a point; Differentiation and integration of simple functions; Kinematics - motion in a straight line, Newton's Laws of Motion, Motion in a two-dimensional plane; Work, power and energy; Impulses; Conservation of momentum; Motion in a circle.

1.4.4 Engineering Sciences (Second Year)

Students carried on with the Mechanics course and the Professional Studies course for the first semester, but the graphics topic was replaced by engineering branch-specific topics where the College students joined the first year main stream engineering students for lectures and tutorials. In the second semester the students continued with their branch specific subjects and some students joined the main stream students for the remainder of the Applied Mathematics course, APPM183, which ran for two semesters, not one, as the Applied Mathematics course APPM182 did.

The branch-specific versions of the Engineering Sciences IB course are given in Appendix 2.

1.5 Courses Taken by Main Stream Engineering students

1.5.1 First Year Main Stream Courses

For study purposes, the Engineering Faculty is divided into six different disciplines at the University of the Witwatersrand although there are many common areas between them in practice. These disciplines or branches are Chemical, Civil, Electrical, Mechanical, Metallurgical and Mining.

All branches took a mathematics course MATH180 and a physics course PHYS180. The Chemical, Metallurgy and Mining branches took the Applied Mathematics course APPM182 while the Civil, Electrical and Mechanical branches took APPM183. APPM182 and APPM183 were the mechanics courses. In the first semester, APPM182 and APPM183 covered the same topics and were taught by members of the Applied Mathematics Department. The second semester of APPM183 was given by the Engineering Faculty staff.

The courses taken by each branch can be found in Appendix 3.

1.5.2 Course Content for APPM182 and APPM183

Applied Mathematics APPM182 and APPM183 :

An Introduction to Newtonian Mechanics:

- Newton's law of Universal Gravitation
- Forces at a Point
- Kinematics
- Newton's Laws of Motion
- Two Dimensional Motion
- Work, Power and Energy
- Impulses; Conservation of Momentum
- Motion in a Circle
- Systems of Coplanar Forces

APPM183 : Relative Velocity; Shearing Force and Bending Moment; Moments of Inertia; Rotation of a Rigid Body.

1.5.3 Second Year Main Stream Courses

The Chemical, Civil, Metallurgy and Mining branches took the Applied Mathematics course APPM280. All branches took mathematics MATH280. All branches except Chemical and Electrical included site visits and vacation work as two of the courses. Appendix 4 contains a list of the courses taken by each branch.

1.5.4 Course Content for APPM280

Linear differential equations with constant coefficients
Simple harmonic motion
Elastic oscillations of a stretched string
Damped oscillations
Forced oscillations
Centres of gravity
Moments of inertia
Rotation of a rigid body
Matrix methods: systems of oscillating particles
Differential equations
Partial differential equations

1.6 Foci of this Research

This is a longitudinal study of some of the students who passed from the College of Science into second year main stream Engineering. The study covers the years from 1994 to1997. The researcher :

1. Compares the teaching methods used in the College and in the mainstream.

2. Compares the College students to the main stream students in terms of pass rates and of the distribution of the final marks for each course.

3. Compares the final marks of the College students who did APPM182 and APPM280 at the end of their first course with their final marks at the end of their second course to see what progress the students have made.

4. Identifies the section of the syllabus from which the questions set in the final examinations for each course are taken. The average marks for each question obtained by the College students who progressed to APPM280 are compared with the average marks for each question obtained by selected groups of main stream students from each year and each course. This comparison is used to see if there are differences according to the section of the syllabus from which the questions were taken. The questions are categorised as bookwork (rote learning of theory) and applications (theory applied to a numerical question). Differences between the average mark obtained in each category by the College students who progressed to APPM280 and the selected groups of main stream students are sought.

5. Categorises the types of answers to examination questions made by the College students who progressed to APPM280 and those made by the selected groups of main stream students and looks for trends in the types and frequencies of answers.

Chapter 2 : Literature Review

2.1 Introduction

Many universities have realised that students experience difficulties with mathematics in their first year at university and there have been many attempts to identify and address the problems (eg Mohammad Yusof and Tall, 1995; Treisman, 1988). The reports about the programmes that have been devised indicate that students are reasonably successful by the end of their first year. Longitudinal follow-up research done on how students cope once the extra support is withdrawn, is scarce.

2.2 Learning and Assessment

Astin (1991) believes that one of the (neglected) purposes of education is talent development and that assessment should be used in such a way as to promote it. "There are essentially two different ways in which assessment activities can contribute to talent development among students : through direct effects on the learner and indirectly by enlightening the educator. ..... Assessment promotes talent development more indirectly when it enlightens or informs the educator about the effectiveness of various educational policies and practices." (p.15). The present study intends to look at the examinations that the students have written in order to gain some indication of the effectiveness of the College programme on students from the Engineering Stream.

Students' learning is affected by the type of assessment that is conducted. Rowntree (1977) states "If we wish to discover the truth about an educational system, we must look into its assessment procedures. What student qualities and achievements are actively valued and rewarded by the system? How are its purposes and intentions realised? To what extent are the hopes and ideals, aims and objectives professed by the system ever truly perceived, valued and striven for by those who make their way within it? The answers to such questions are to be found in what the system requires the students to *do* in order to survive and prosper. The spirit and style of student assessment defines the *de facto* curriculum." (p.1). It may be that there are differences in teaching and assessment methods between College and second year main stream that ex-College of Science students are not coping with, and which contribute to a lack of success.

2.3 Disadvantaged Students and Support Structures

Jawitz (1992) found that many black first year Engineering students at the University of Cape Town experience problems that significantly affect their performance in first year. He found that students who wrote the matric exams administered by the then Black education departments performed significantly worse than students from white education departments in every first-year engineering course. The College students from 1992 to 1998 were mostly from DET and then former DET schools (70 - 80%). The aim of the College is to prepare students who would not normally be admitted to the university to be able to cope in the main stream from second year onwards by providing them with academic help and by providing counsellors to help with other practical and emotional problems.

Rutherford and Matlou (1996) in College of Science Annual Report 1996 (1997) summarise the students accepted into the College as having the following traits:

"a) the first in their family to attend university

b) unfamiliar with a larger city environment

c) unfamiliar with the large university campus

d) English second language speakers

e) not aware of student services on campus

f) lacking information regarding university work requirements (both quantity and quality), courses available and their pre-requisites and possible careers." (Appendix 2, p.7)

The College students may well have parallel experiences to American students who are also the first in their families to attend university. In America, the under prepared students come from the minority groups (Black, Hispanic, Native American), so much of the literature in this area focuses on Minority Students. The students have to cope with many cultural and ethnic issues which their family life has not prepared them for and consequently find difficulty in turning to their families for help and support (Zwerling and London, 1992; Terenzini, 1995). Hsiao (1992) in reviewing Zwerling and London (1992) remarks that "In addition to being less prepared academically, such students often have insufficient knowledge of time-management techniques, the economic realities of college life, and the impersonal, bureaucratic nature of educational institutions. Among the strategies which colleges can employ to assist first-generation students are:

(1) specialised outreach, tutoring, and mentoring programs;

(2) bridge programs, linking high schools and post-secondary institutions to help students confront the obstacles to successful college preparation;

...... In order for this high risk group to succeed in their academic endeavours, colleges must provide a range of programs and services to counteract the weaknesses many of them bring to higher education and to help them overcome the obstacles they face once they enrol." (p. 1).

The College of Science students were part of an initially minority black population at the University and the College attempts to redress similar inadequacies that students bring with them and which would cause them to flounder at a university. A measure of the success of the College programme lies in the degree of success of students who have continued into the main stream courses.

The way in which students feel they are treated and viewed and the facilities available to them to help them deal with problems of all sorts is likely to affect the level of achievement (Adams, 1991). College students are given a special place at the university which is intended to help them overcome the factors which hold them back. Once they leave the College, they are expected to be able to cope using the same facilities available to main stream students. The College experience should be such that students are gradually weaned from receiving support in many areas (some of which are areas in which they are not even aware of having a need) to being able to identify needs for themselves and knowing how to deal with the problems.

The College of Science Annual Reports (Rutherford, 1995,1996, 1997,1998) all contain a section within which the counselling activities and services are reported. The College organises an orientation programme for students, helps with curriculum planning and career information and gives counselling to students on other matters. The counsellor keeps a record of the kind of counselling that occurs. By far the most counselling sessions are about financial matters, followed by career advice and curriculum planning, and accommodation matters. The fewest number of consultations took place about academic matters, appeals and exclusions, alternative careers and transfers, and personal and family matters.

2.4 Retention Rates

Smith (1995) studied retention and graduation rates of under represented minority students during 1985-91 with first-time freshman cohorts at 67 US Colleges and Universities. Data were also collected from 17 institutions for science, engineering and mathematics majors by race and gender. Six-year tracking of the 1985 and 1986 cohorts of 312 795 first-time freshmen indicated that retention rates were 73% for Blacks, 72% for Hispanics and 69% for American Indians compared with 81% for the other ethnic groups; after the second year, the retention rates were about 59% for Blacks, 62% for Hispanics and 54% for American Indians. This seems to indicate a trend of dropping retention rates in second year.

The College of Science Annual Reports (Rutherford, 1995,1996, 1997,1998) contain information about student progress that keeps track of numbers of graduating students. For the students who started Engineering in the College, these reports indicate a declining retention rate after the end of second year main stream.

Hayden and Holloway (1985) concluded that a lack of information about the nature of engineering appears to influence retention of students. " Students that drop out do not have realistic expectations about engineering education. .... A second factor influencing student attrition was academic style. It seemed that successful engineering students preferred a more structured program. Educators might consider if highly structured curricula are necessary in engineering education and whether such programs attract students that make better engineers." (p. 668).

Friedman and Caset (1990) recommend that "existing support programs for minority engineering students should be evaluated to determine which components are most effective and where additional resources are required. As indicated by students in this sample .... MEP [Minority Engineering Program] services did not seem to have a substantial impact on student achievement. .... stronger and more effective support systems can be built to ensure retention and graduation of minority students accepted into engineering programs." (p. 412).

2.5 Teaching Styles

Wankat and Oreovicz (1994) note that "For most engineering professors, lecturing is synonymous with teaching. While it can be effective for certain kinds of learning, research has shown that lecturing is not the best method for meeting higher cognitive objectives such as critical thinking." (p. 15). They advocate the use of discussion and cooperative group methods. This type of teaching was being used in the College part of the Mechanics course, but the researcher wished to establish whether similar methods were used in second year mainstream in 1995, 1996 or 1997.

Hauser *et al.* (1995) report on three engineering students and their instructor examining many aspects of undergraduate engineering instruction and suggesting ways to improve it. On the subject of lectures, the students say "Lectures should not be frantic, one-hour stenography lessons where students are more intent on copying information than understanding it." (p. 22). The instructor says "A lecturer should simplify the concepts, put a perspective on the material, get the students thinking, and make them want to learn more." (p. 22).

Florida State Postsecondary Education Planning Commission (1993) identified some outstanding efforts to improve science and mathematics at the post secondary level and findings included

(1) improvement is most effective when supported by an institution-wide commitment,

(2) courses must be restructured to reflect a more active hands-on approach to learning that reflects real world applications,

(3) faculty members should be hired who reflect the new approaches to teaching in these areas.

The College reflects these three criteria, so it should be expected that the abilities of the students improve during the time they spend in the College. The question is whether the improvement is sufficient to enable them to cope in second year mainstream.

When examining the literature on cognitive variables that affect academic performance in engineering Potter and van der Merwe (1993) found that some literature indicated that "the demands of the engineering curriculum at levels beyond first year were very different to those of the first year. It was therefore particularly important that the engineering student learned a variety of problem solving strategies in order to cope effectively with the different types of academic problems presented in his various university courses. .... The literature on prediction of (particularly) black student samples was consistent in indicating low statistical relationships between traditional cognitive predictors and academic performance." (p. 34).

Rutherford and Donald (1993) state that "The College of Science has pointed the way to increasing the number of non-traditional, educationally disadvantaged students who succeed at first year university level. The general consensus seems to be that these students are more motivated, more questioning and more interested in serious study than many of the traditional university students." (p. 214).

Chapter 3 : Methodology

3.1 Introduction

In addressing the foci of the research a multi-method approach was used. Records kept by the University and by the researcher were consulted; answers to examination questions were analysed and lecturers were consulted. It was not possible to take random samples as would normally be done in order to use statistical methods of analysis. Also, the number of College students is small, so the usual statistical techniques are not appropriate.

3.2 Research Focus 1 : Teaching Methods

The researcher was the lecturer for the College courses and can report on the teaching methods used from her own records. The first and second year teaching methods were researched by the researcher attending several lectures and by asking the lecturers for clarification about the way tutorials were organised.

3.3 Research Focus 2 : Pass Rates and Distribution of Final Marks

Final marks for the Engineering Sciences course and the APPM182 and APPM280 courses were obtained from the University archives. The final marks for the College mechanics course were obtained from the College records.

The final marks of the APPM182 and APPM183 courses and the final mark of the mechanics courses (rather than the Engineering Sciences marks) were used to calculate pass rates and were also used as an indication of where the College students were ranked in the class of main stream students at the end of first year.

The final marks of the APPM280 course were used for the same purposes. The ex-College students were identified and a pass rate for them was calculated. The pass rate of the remaining students was calculated.

3.4 Research Focus 3 : Progress of the College Students

3.4.1 The Selection of the College students and the Main Stream Students

The students chosen were College of Science students who took the Engineering Sciences option and then went on to do Applied Mathematics (APPM280) in the second year of Engineering; and students from first year Engineering and second year Engineering. The students who are not ex-College students are referred to as main stream students.

The **first year** year-groups were selected as follows : the ex-College students in the APPM280 courses of 1995, 1996 and 1997 were identified. Their answer books from the first year examinations in 1994, 1995 and 1996 were found The examination answer books from several main stream students (from the corresponding year) with the same mark as, or a mark differing by no more than 2 from the College students, were selected for each year. (Note : the College students and the main stream students wrote the same examination paper.)

The **second year** year-groups were selected as follows : The ex-College students' answer books for the APPM280 final examinations in 1995, 1996 and 1997 were found. Answer books from main stream students with the same mark as, or a mark differing by no more than 2 from the College students, were selected for each year, except in the cases of 94/5C, 94/5E and 94/F in APPM280 1995 and 96/7C in APPM280 1997 where it was not possible to get more than one other answer book with a mark within 2 of the ex-College student's mark.

Each year-group was subdivided by grouping each ex-College student with the corresponding mainstream students.

From this point onwards the ex-College students in the APPM280 course will be referred to as College students.

3.4.2 The Progress of the College Students

The examination mark of APPM182, the final mark for the College mechanics course, the Engineering Sciences mark and the examination and final mark from APPM280 was recorded for each of the College students in the groups to assess their progress over the two courses.

3.5 Research Focus 4 : Comparing Average Marks for Questions in the Examinations

3.5.1 Course Descriptions

The course descriptions of the first and second year main stream courses were obtained from the lecturers. The sections of the syllabus from which the questions were taken were identified as in the course content listed in Chapter 1 Introduction, pages 8 and 9.

3.5.2 Data Collection

The mark for each question as a whole for each student in the year groups was recorded. In each year group, the mean mark of the College students and of the main stream students for each question was calculated and tabulated. The section of the syllabus from which the question came was identified according to the topics listed in the syllabi.

The answer books of each student in each year-group were examined. The answers to each part of each question were examined and the answers were categorised as follows :

Correct : The student got full marks for the question.

Careless : An error was classified as careless if

- an arithmetic error occurred eg $2x3 = 5$.
- an algebraic error occurred eg $(a+b)^2 = a^2 + b^2$.
- something was omitted between one logic statement and the next eg an exponent was omitted; a symbol was lost from one line to the next.
- values were copied incorrectly from the question paper.
- "Bookwork" was not written down correctly, and thus the student's wording did not convey the concept precisely, eg *bodies* used instead of *spheres* in Newton's Law of Impact.

Incomplete : The student started to answer the question but did not arrive at an answer:

- a diagram was given but no working followed.
- it was clear that the student was working on the question when the exam ended (remarks such as "no time" written by student).
- the student stopped working before reaching an answer.

Concept : The student used an incorrect approach to the question eg used work principles instead of energy principles; conservation of energy assumed where not appropriate.

Omitted : The question was not attempted at all - either the number of the question was written down with no working of any kind to follow, or the question was not written into the answer book at all.

The marks and answer category for each sub-section of each question for each student was recorded.

The sub-sections of the questions were categorised as bookwork or applications and the average marks for all the selected College students and all the selected main stream students across the three years in APPM182 and in APPM280 were calculated.

A selection of the tables that were generated in doing this research can be found in Appendix 8.

3.6 Research Focus 5 : Answers to Examination Questions

The number of answers in each category was added up for each student, and then for each of the College and main stream groups in each year-group. In order to compare the College group with the main stream group in each year, the totals of the mainstream group were divided by a factor which "calibrated" the totals to that of a group size equal to the size of the College group.

Chapter 4 : Results

4.1 Introduction

In this research report the first year course will be referred to as APPM182, and refers to the course which preceded the examination written by both the College students and the main stream students (APPM182 and APPM183) in June of 1994, 1995 and September of 1996. For an explanation of the course codes see Appendix 5. The examination in 1996 was written in September in order to give the main stream students an extra half-semester for revision because it was felt that the pass rates in previous years had been too low.

4.2 Research Focus 1 : Teaching Methods

4.2.1 First Year College Mechanics

The content of the mechanics course that the students took in the College was in essence the same as the Applied Mathematics course given to the first year Engineering students who took APPM182. The College students had one and a half years to complete this course. In 1992 and 1993 the entire time period was used for the course content and was found to be more than sufficient, so from 1994 additional material and activities designed to expose students to facets of engineering were added to the course in the first semester. There were still two semesters available for the course content to be taught in, compared to the one semester allocated to the main stream students.

In the first year of the College mechanics there were two 90-minute teaching periods per week allocated to the course. In 1992 and 1993 teaching of the course material started in the first semester of the year, but from 1994, the course proper started in the second semester of the year. The students were placed in groups of four in a venue with movable, flat desks. The students were assigned to groups by the lecturer at the beginning of the first teaching semester, but at the end of the teaching quarter (half a semester) the students were invited to change their groups if they wanted to. The members of the groups were selected more or less randomly, but an effort was made to put at least two women together in any group.

The teaching time was a mixture of lecture time and tutorial time in each double period. The course started with a series of modules developed at the University of Wisconsin, and designed for discussion in groups. The modules covered vectors, kinematics and forces and problem-solving skills. The work was at a pre-calculus level and was used to reinforce aspects of mechanics that should have been covered in the high school syllabus. The topics were also selected in areas where many students have alternative conceptions, and were designed to help students relearn the concepts correctly. Each module was introduced by the lecturer and then the students spent all or most of the rest of the 90-minute period working on the module. At the end of the period, or at the beginning of the following period, the lecturer went over the answers and highlighted important points. The modules took one quarter (half a semester) to complete.

Three tutors (post-graduate students from the Department of Computational and Applied Mathematics) were available to help students. The tutors were chosen because they were competent in mechanics and because they expressed an interest in teaching the College students. They were always well prepared. The tutors were encouraged to ask probing questions which would enable the students to come up with their own answers, rather than to supply the students with the answers.

The topics listed as the course content in the Introduction (page 8) were covered after the modules were completed. The part of each topic to be covered in each teaching session was introduced with a short lecture, 20 to 30 minutes long, and the students were then given work sheets in which the questions and information reminded them of what was in the verbal introduction. The worksheets were designed to challenge the students to explore the topic further by using prior knowledge and problem solving skills. After the students had completed a task, the class was again addressed by the lecturer in order to draw attention to points made in the worksheets or to give answers or to engage the class in a discussion about the worksheets and/or to move on to the next part of the topic under discussion.

At the end of a topic the students were supplied with photocopied notes based on and almost identical to the lecture notes given verbally in lectures to the mainstream students. The photocopied notes had been prepared by the College lecturer in such a way that there were gaps which needed to be filled in by the students. This was done during a lecture period where the lecturer went through the notes. The purpose of the notes was two-fold - firstly they gave the students a summary of the topic and secondly they ensured that the College students had the same material as the main stream students. The changes made to the main stream lecture notes were usually in simplifying the English and some of the mathematics.

The students were encouraged to talk (in their groups) about the problems on the worksheets and occasionally worksheets were taken in and marked. The main purpose of getting students to talk about mechanics was to encourage them to use English, although they were welcome to use their mother-tongue, especially at the beginning of the year. Talking about mechanics also caused students to verbalise alternative conceptions which could be addressed either by their peers or the lecturer or the tutors. Group work also gave the more advanced students the opportunity to teach their peers and thus enhance their own learning.

Unsupervised work that had to be handed in was set occasionally and marked by either a tutor or the lecturer. Tests were given at the end of each topic and an examination was set in November.

4.2.2 Second Year College Mechanics

In the second year of the College, the format of the teaching time in the mechanics course changed. The students had one 45-minute period on Mondays, Tuesdays and Wednesdays and a double (90-minute) period on Fridays. The time spent lecturing was longer and the time spent doing tutorial questions was shorter during the three single periods than it had been in first year. The lecturing time was increased gradually until by the end of the first quarter the lectures were 45 minutes long. The double period was used purely as a tutorial period from the beginning of the year, and by the end of the first quarter it was the only tutorial time. The venue had flat, movable desks. The 4-person group structure was maintained and encouraged but not enforced, although students tended to sit facing the lecturer rather than facing each other.

In some topics the lecture notes were handed out at the beginning of the topic and filled in as the new material was presented. The tutorials served to give practice examples similar to those in the notes and to give problems which required problem solving skills. The students still worked in groups although group work was rarely handed in. Two tutors were available during the tutorial times. The tutors usually attended the lecture sessions as well.

Unsupervised work was set almost every week, and handed in to be marked by the tutors. Tests were given at the end of each topic. The examination at the end of the course (in June of 1994 and 1995 and in September of 1996) was the same as the one the main stream students wrote. They all wrote in the same venue at the same time.

4.2.3 The First Year Main Stream Courses

The main stream APPM182 course was half a year (one semester) long. The main stream APPM183 course was two semesters long, but the contents of the first semester were the same as the APPM182 course. The second semester was taught by lecturers from the Engineering Faculty, not the Computational and Applied Mathematics Department. All students wrote the identical exam at the end of the first semester.

The class was divided into three groups, with one APPM182 group and two APPM183 groups. The groups were large - over 100 students per group. All the groups had lectures and tutorials in the same time slots on the timetable. There were three 45-minute lecture periods and one 90-minute tutorial period per week.

During the lectures the lecturers either dictated the notes or wrote them on the board and gave extra clarification where necessary. There were worked examples in the notes. The notes followed the text book "An Introduction to Newtonian Mechanics" by R.M. Walker and J.C. Faulkner. Mr. Faulkner is at present (2000) still a member of the Department of Computational and Applied Mathematics at the University of the Witwatersrand and lectured the mechanics course from its inception. Dr Walker was a member of the Department until his retirement in 1994 and also lectured the course until that time.

For the tutorials, the class was further subdivided into groups of about 20 each with a tutor. The tutors were senior students from the Department of Computational and Applied Mathematics or from the Engineering Faculty. The tutorials were compulsory and registers were taken. A student attending less than 80% of the tutorials was in danger of being refused admittance to the examination.

The questions answered in the tutorials were taken from the text book and were assigned during the lectures to give the students time to attempt them before attending the tutorial. The students were supposed to come to the tutorials with questions about the work they had already attempted, but in reality, most students attempted the assigned work for the first time during the tutorials. The tutors helped the students individually. Many of the tutors were insufficiently prepared for the tutorials even though they had been supplied with solutions to the assigned questions and had been informed before the tutorial about which questions had been assigned to the class.

The class was given two tests and an examination.

4.2.4 The Second Year Main Stream Course

The course was given in the second semester of the year. There were four 45-minute lecture periods and one 90-minute tutorial period per week. The College students were not identified to the lecturer and received no special treatment.

In 1995 the course was lectured by Mr. George Buric and in 1996 and 1997 by Prof. David Block. Prof. Block based his lectures on the lecture notes prepared by Mr. Buric, the basic content of the course having been approved by the Engineering Faculty.

During the lectures the lecturer either dictated the notes or wrote them on the board and gave extra clarification where necessary. There were worked examples in the notes. Students tutors were available to help at the tutorials. Students were given examples during the lecture and told to prepare them for the tutorial. At the tutorial they were given further questions. One of the questions was normally handed in to be marked. The students normally had to hand the question in at the end of the tutorial, but for more time-consuming examples they were given a week to complete the question. The tutors marked the work that was handed in.

4.2.5 Calculation of Final Marks

The final marks for the College mechanics course and APPM182 were calculated by taking 60% of the final examination mark and 40% of the year mark. In the case of the main stream students, the year mark was obtained from two tests written during the semester. In the case of the College students, the year mark was obtained from their mark from first year (College) and several tests as well as unsupervised work assignments. Mainstream students passed or failed according to their final mark for APPM182. College students passed or failed according to their Engineering Sciences mark which consisted of the final mark from the mechanics course and marks from two or three other components, depending on which branch of Engineering they were registered for. (See Appendix 6.) This meant that while some students who failed the mechanics course in the College passed because of their Engineering Sciences mark, others who had passed mechanics but failed one or more of the other courses and thus failed Engineering Sciences, did not proceed to second year.

The APPM280 final mark was a combination of a year mark obtained from two tests and some unsupervised work assignments (one third of the final mark) and the examination mark (two thirds of the final mark).

4.3 Research Focus 2 : Pass Rates and Distributions of Final Marks

4.3.1 APPM182 Pass Rates

Table 4.1 shows that in all three years the College pass rate is lower than the main stream rate, however it is only in 1994 that there is a material difference between the groups. In 1996 the pass rates for both groups are appreciably higher than in the previous two years. The increase is possibly due to the extra time allocated to revision and examination preparation in 1996.

	1994	1995	1996
College	40.8% (49)	60.5% (43)	83% (48)
Main Stream	67.4% (341)	64.3% (398)	84.7% (287)

Table 4.1 **Pass rates for College of Science Mechanics and APPM182.** Numbers in brackets are the total number of students in a group.

4.3.2 APPM182 1994: Distribution of Final Marks

%	1-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	90-100
College 49	0	0	2 4.1%	15 30.6%	12 24.5%	16 32.6%	3 6.1%	1 2%	0	0
Main Stream 341	0	5 1.5%	12 3.5%	35 10.3%	60 17.6%	120 35.2%	63 18.5%	35 10.3%	8 2.3%	3 0.9%

Table 4.2 **Final Marks : College of Science Mechanics and APPM182 : Number of students and percentage of group in each mark range : 1994**

The distribution of College marks is markedly skewed to the left : 59.2% of the class got below 50% compared to 32.9% of the mainstream class. The percentage of both groups in the 50% to 60% range is approximately the same. In the range over 60%, the College group is much more curtailed than the mainstream group, with the remaining 8.2% of the students in the 60% to 79% range whereas the remaining 32% of the mainstream class are in the 60% to100% range.

4.3.3 APPM182 1995 : Distribution of Final Marks

%	1-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	90-100
College	0	0	1	6	10	15	7	3	1	0
43			2.3%	13.9%	23.3%	34.9%	16.3%	6.9%	2.3%	
Main Stream 398	0	8 2%	23 5.8%	50 12.5%	71 17.8%	149 37.4%	63 15.8%	33 8.3%	7 1.7%	4 0.1%

Table 4.3 Final Marks : College of Science Mechanics and APPM182 : Number of students and percentage of group in each mark range : 1995

The spread of College marks is better in this year than in 1994, from 20% to 89% as compared with 20% to 79%. 39.5% of the College students got below 50%, compared to 38.1% of the main stream students, ie there is hardly any difference between the groups. There is a slightly higher percentage of main stream students in the 50%-59% range and in the 70%-79% range, but the 60%-69% range has a small difference in favour of the College students. There are 2.3% of the College students above 80% compared to 1.8% of the main stream students.

4.3.4 APPM182 1996 : Distribution of Final Marks

In Table 4.4 which follows, the spread of the College students is from 30% to 89%, whereas the main stream students are in the 10% to 100% range. In the range below 50% the total percentage of the two groups is close, 16.6% for the College group and 15.15% for the main stream group. The College students are concentrated in the 50% to 69% range (70.8% of them) while 52.6% of the main stream students are in the same range. The remainder of the College students (12.4%) are in the 70% to 89% range but the remaining 31.9% of the main stream students are in the 70% to 100% range.

%	1-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	90-100
College 48	0	0	0	1 2%	7 14.6%	18 37.5%	16 33.3%	5 10.4%	1 2%	0
Main Stream 287	0	1 0.35%	9 3%	11 3.8%	23 8%	62 21.6%	89 31%	68 23.7%	22 7.6%	2 0.6%

Table 4.4 **Final Marks : College of Science Mechanics and APPM182 : Number of students and percentage of group in each mark range : 1996**

4.3.5 APPM280 Pass Rates

Table 4.5 shows that there is very little difference in the pass rates of the College students in 1995, but in 1996 and 1997 there is an appreciable difference. The small size of the College groups causes the apparently large fluctuation in pass rates. At a macro level, in terms of passing, College students appear to cope as well as main stream students with APPM280.

	1995	1996	1997
College	83.3% (6)	100% (5)	71.4% (7)
Main Stream	82.9% (88)	77% (100)	84.3% (102)

Table 4.5 **Pass Rates for APPM280.** Numbers in brackets are the total number of students in a group.

4.3.6 APPM280 1995 : Distribution of Final Marks

%	1-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	90-100
College	0	1	0	0	0	2	2	1	0	0
6		16.7%				33.3%	33.3%	16.7%		
Main Stream 91	0	1 1.1%	1 1.1%	7 7.9%	6 6.8%	25 28.4%	27 30.7%	14 15.9%	4 4.5%	3 3.4%

Table 4.6 **APPM280 : Final Marks : *Number of students and percentage of group in each mark range* : 1995**

The College group is very small, with only one student failing and the rest in the 50% to 79% range. The mainstream group is big, and the marks cover the range from 10% to 100%, with the majority of students clustered in the 50% to 79% range. Both groups are thus concentrated in the same range. Both groups are skewed to the right.

4.3.7 APPM280 *1996* : Distribution of Final Marks

Table 4.7 shows that the small group of College students are clustered in the 50% to 79% range as they were in 1995. The much larger main stream group has the majority of its students in the same 50% to 79% range, with more students in the range below 50% than in the range above 80%. The College students are equivalent to the middle majority of the main stream students.

%	1-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	90-100
College 5	0	0	0	0	0	2 40%	2 40%	1 20%	0	0
Main Stream 100	1 1%	3 3%	2 2%	7 7%	10 10%	21 21%	25 25%	25 25%	5 5%	1 1%

Table 4.7 APPM280 : Final Marks : Number of students and percentage of group in each mark range : 1996

4.3.8 APPM280 1997 : Distribution of Final Marks

%	1-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	90-100
College 7	0	0	1 14.3%	0	1 14.3%	2 28.6%	2 28.6%	1 14.3%	0	0
Main Stream 102	0	1 0.98%	1 0.98%	7 6.8%	6 5.9%	28 27.4%	29 28.4%	21 20.1%	6 5.8%	3 2.9%

Table 4.8 APPM280 : Final Marks : Number of students and percentage of group in each mark range : 1997

The College students, with the exception of two, are all in the 50% to 79% range. The other two students are in the 20% to 49% range. The majority of the main stream students are in the 50% to 79% range as well, repeating the pattern of the previous two years. There are more main stream students in the range below 50% than there are in the range above 80%. The College group is so small that no tailing off happens outside the middle range. Again it can be seen that the College students are equivalent to the middle majority of the main stream students.

4.4 Research Focus 3 : The Progress of the College Students

In Table 4.9, the codes for the individual students indicate the year they wrote APPM182 and the year they wrote APPM280, for example 94/5C is a student who wrote APPM182 in 1994 and APPM280 in 1995.

In 1995, the only failure at the end of APPM280 was a student (94/5E) who would have been excluded if s/he had been a main stream student. Compare this with 94/5F who would also have been excluded if s/he had been a main stream student, but managed to pass extremely well at the end of APPM280. The difference may lie in circumstances such as motivation, pressures from living conditions, level of basic mathematics comprehended, understanding of teacher/lecturer due to fluency and comprehension of English. 94/5B, 94/95C, 94/95D and 95/96E had very bad examination marks for APPM182, but passed according to the final mechanics mark and the Engineering Sciences mark and then went on to pass APPM280.

96/7E probably did not cope with some external factors in his/her life since the examination mark for APPM182 and final marks for Mechanics indicate a level of competence on a par with that of others who passed the APPM280 course. 96/7G must have had problems during the semester with his/her tests since s/he passed the APPM280 examination, but failed on the final mark. 96/7G's marks from APPM182 would be classed as indicating that the student would be likely to struggle to pass APPM280.

Students	Exam Mark APPM182	Final Mechanics Mark	Engineering Sciences Mark	Exam Mark APPM280	Final Mark APPM280
94/5A	51	60	54	51	57
94/5B	44	62	70	64	67
94/5C	43	58	57	41	50
94/5D	37	55	68	67	62
94/5E	27	49	51	9	19
94/5F	24	46	55	86	71
95/6A	71	75	66	78	72
95/6B	61	70	69	74	69
95/6C	57	68	65	75	63
95/6D	53	62	60	61	58
95/6E	36	50	56	58	55
96/7A	68	62	64	72	74
96/7B	66	59	51	53	50
96/7C	65	61	52	71	61
96/7D	61	61	52	54	53
96/7E	60	56	53	25	29
96/7F	55	57	51	64	65
96/7G	52	55	52	53	48

Table 4.9 **Marks obtained by college students in various sections of courses by year group. Marks are given as %.**

Of those who passed according to the final mark for APPM280, six students increased their marks compared to the final mark for mechanics in the College. The increases range from 5% to 25%. Eight students' marks decreased between the final mark for mechanics in the College to the final mark for APPM280. The decreases ranged from 1% to 9%. One student's mark remained the same.

Also of those who passed according to the final mark for APPM280, one would have been excluded if s/he had been in the main stream in first year and five had marks in the 50 to 59% range for APPM182, which implies that they are coping at a level that is only just adequate for first year. The three who failed APPM280 had marks of 56%, 55% and 49% for the final College mechanics mark

4.5 Research Focus 4 : Comparing Average Marks for Questions in the Examinations

4.5.1 Selection of Main Stream Students and Other Notes

In Research Foci 1 and 2 the whole class of students was considered. In this Research Focus the selected groups of main stream students and College students are considered. The College students are the ones who took APPM280 as one of their second year main stream courses. For APPM182 and APPM280, the main stream students were selected because they had total marks for their examinations which were very similar to or identical to the College students.

In the tables that follow (Tables 4.10 to 4.15), the column headed Total is the average mark for the whole examination for the selected groups of students. The College average is almost the same as the main stream average because the main stream students have been selected to have marks very close to the College students' marks.

A copy of each examination paper can be found in Appendix 7.

Comments about the sub-sections of the questions in the examination papers are to be found after each table and are based on the analyses done to identify the types of answers students gave to the examination questir ~s.

4.5.2 APPM182

Table 4.10 shows that the College students seem to be able to answer Question 1 on Work, Power and Energy and Question 2 on Impulse better than the main stream students. Both these questions resemble tutorial questions very closely and it is possible to use a formalised approach to them.

1994	Q1 [25]	Q2 [25]	Q3 [25]	Q4 [25]	Total
College (6)	8.83	14	10.83	4	37.66
Main stream (36)	6.38	12.72	13.53	5.29	37.64

Table 4.10 **Mean marks for questions in the 1994 APPM182 examination. Marks given out of the total for the question.**

Question 3, the Newton's Law of Universal Gravitation and Circular Motion question had a bookwork section which three of the College students answered well and three did not. The second part of the question is about Mars and its moons. The College students did not answer it well, three of them making concept errors and the others making careless errors. The main stream students mostly made careless errors.

Question 4, on the Equilibrium of Coplanar Forces, required a diagram to be drawn from a written description. Four College students got the diagram wrong, one omitted the question and one made a concept error. The main stream students coped better than the College students, but many struggled to draw the diagram correctly, or made concept errors.

1995	Q1 [13]	Q2 [22]	Q3 [15]	Q4 [25]	Q5 [25]	Q6 [6]	Total %
College (5)	4.2	14	13.6	14.8	9	0	55.6
Main stream (29)	5	13.5	12.55	12.65	11.12	0.9	55.24

Table 4.11 **Mean marks for questions in the 1995 APPM182 examination. Marks given out of the total for the question.**

Question 1, based on Work, Power and Energy, is the same as one done in lectures. None of the students answered this question well, the majority making concept errors.

Question 2, about the Conservation of Momentum is similar to one asked in a tutorial, but had not been seen by the students before. The college students coped marginally better than the main stream students, the errors being concept or careless algebraic.

Question 3 on Impulse is identical to one in the text book and was answered very well by all the students. The errors that occurred were in general careless arithmetic ones.

Question 4a is a bookwork question, requiring students to find the magnitude and direction of the acceleration of a particle moving with constant angular velocity on a circle. Most of the students answered it in a careless, incomplete manner, and the rest had no idea where to start. Question 4b is similar to a tutorial question, but required the principles of motion in a vertical circle to be applied carefully. Twenty one of the students got 10 or more marks out of 15, the errors being careless ones, while the remaining thirteen students (including one College student) made concept errors and got less than three marks.

Question 5a, proving the Theorem of Moments, was answered badly by all, there being seven students who omitted it. Question 5b requires a diagram to be drawn from a description and the application of the theorem just proved. It is similar to a tutorial question. Many students did not get the diagram correct and many made concept errors. Only two people, one College student and one main stream student, got full marks.

Question 6, showing conservation of momentum in an isolated two-particle system, was for extra marks and was either omitted or not completed by all the students. The highest mark was 4 out of 6. The question is bookwork.

1996	Q1 [22]	Q2 [24]	Q3 [22]	Q4 [26]	Q5 [26]	Total [120]	Total %
College (7)	14.14	18.28	11.86	16.14	12.71	73.14	60.95
Main stream (37)	15.38	19	12.73	14.59	11.89	73.59	61.33

Table 4.12 Mean marks for questions in the 1996 APPM182 examination. Marks given out of the total for the question.

In Question 1a, where students were asked to state Newton's Law of Universal Gravitation, five of the seven College students got full marks and the other two made careless errors. The majority of the mainstream students also got full marks. Question 1b is identical to a tutorial example. It required the application of Newton's Law of Universal Gravitation and the students coped well with the calculation, but many were unable to comment accurately on their results. The main stream students outperformed the College students slightly

Question 2a, a simple kinematics question, was answered correctly by all the College students and by the majority of the main stream students. Question 2b, an extension of the question in part (a) was answered correctly by five of the seven Colleges students, and by 28 of the 37 main stream students. Question 2c is an application of the previous two questions. The College students made careless errors or left the question incomplete. The main stream students made mainly careless errors, with some concept errors. There is very little difference in the main stream and College average mark.

In Question 3a students were asked to prove the work-energy relation. Five of the seven College students got full marks and so did 16 of the 37 main stream students. The College students coped less well than the main stream students with Question 3b which is an application of the work-energy relation and similar to a lecture example.

Question 4a requires the projectile motion equations to be written down form memory, i.e. it is a bookwork question. All of the College students bar one got full marks. The main stream students also either got full marks or made small careless errors. Question 4b is an example of projectile motion and is similar to tutorial questions. The majority of the students answered this question very badly, with many careless errors. Only 4 mainstream students got full marks for the question. In Question 4c the students had to apply energy considerations to the projectile motion problem. Students either omitted the question or answered it badly (28 out of 44 students) or answered correctly (16 out of 44 students). Overall the College students were slightly better than the main stream students in Question 4.

Question 5a asked students to write down the two equations governing the direct impact of two spheres and to explain them. Most students were careless in their wording and had trouble giving a good diagram. Question 5b is a direct application of Question 5a and is similar to tutorial questions. The College students managed to get a slightly better average than the main stream students on the question, both groups making mainly careless errors. Overall, the College students had a slightly better average on Question 5.

4.5.3 Summary

There is no clear pattern of College students being better than mainstream students in any particular topic of the syllabus, or vice versa. However, in all three years the College students outperformed the mainstream students slightly in the questions from the section on Impulses. The only other differences worth noting occurred in the Work, Power and Energy section, in the Newton's Law of Universal Gravitation and Circular Motion section, where the College students outperformed the mainstream students once and the reverse happened twice.

Analysing the questions as bookwork and applications showed that both the College students and the main stream students have approximately the same average mark for both categories.

4.5.4 APPM280

1995	Q1 [27]	Q2 [18]	Q3 [22]	Q4 [23]	Total %
College (6)	10.33	9.83	13.66	13.83	52.96
Main stream (38)	13.1	9.71	18	14.81	56.08

Table 4.13 Mean marks for questions in the 1995 APPM280 examination. Marks given out of the total for the question.

Question 1a, from Centres of Gravity is bookwork which the students were aware was a very likely examination question. Two of the College students got full marks, one made a minor careless error and the other 3 got 0 because of concept errors. The mainstream students show a similar mix of answers : 16 getting full marks and the rest making careless or concept errors. Question 1b, from Rotation of a Rigid Body, is also a bookwork question. Three of the College students got full marks, one got 1 mark and the other two got 0 because of concept errors. Question 1c was an unseen question and required students to apply theory from Moments of Inertia. The whole group except two main stream students made concept errors or left it incomplete. Question 1d from the section on small oscillations is similar to one given in a tutorial. Three College students made only minor careless errors, one made a more serious careless error, one made a concept error and one omitted the question. The first two sub-groups of main stream students also made minor careless errors, but the majority of the rest made many careless errors. The overall effect was that the mainstream students have coped with this entire question better than the College students.

Questions 2a and 2b, bookwork questions about matrices, and 2c, finding the inverse of a matrix were done well by almost the entire group, but question 2d was not answered well by almost the entire group. It is also a bookwork question about matrices and is one that appears regularly in past examination papers. One College students got full marks and the rest made concept errors. Four main stream students got full marks and most of the rest made concept errors. There is virtually no difference in the overall average on this question between the College and main stream students.

The College average mark for Question 3, from the section on Matrix Methods: systems of oscillating particles, was affected by the fact that one student omitted the entire question. Without this mark, the average becomes 16.4 which is a lot closer to 18 than 13.66 is. One of the remaining 5 College students made several concept errors, but the others made small careless errors. The mainstream students coped very well with this question, the errors being mainly careless and incomplete, with a few concept errors as well. It is a question similar to a tutorial question and the students were aware that it was a likely examination question.

In Question 4, a two point boundary value problem, the College and the main stream students made much the same errors, these being mainly careless, incomplete and omitted. The two sub-groups of students with the lowest marks made concept errors and omitted the more difficult parts of the question. Question 4a is bookwork and Question 4b is similar to an examples in the notes and to a tutorial example.

1996	Q1 [40]	Q2 [40]	Q3 [40]	Total [120]	Total %
College (5)	20	25	38.4	83.4	69.5
Main stream (28)	20.86	29	31.93	81.93	68.27

Table 4.14 Mean marks for questions in the 1996 APPM280 examination. Marks given out of the total for the question.

Question 1a and 1b were bookwork questions about Simple Harmonic Motion and most of the students got them correct. Questions 1c and 1e were not well answered by the group, these being an application of Simple Harmonic Motion and Vector-matrix bookwork. The errors made by the College students and the main stream students were concept, careless and incomplete. Question 1d, a second order differential equation, is similar to an example given in the notes and in the tutorial. Only one main stream student got the question correct; all the other students made careless or concept errors. There is very little difference in the average marks for the whole question between the College group and the main stream group.

Question 2a is similar to a tutorial example and required the students to apply Simple Harmonic Motion theory. Most of the students got full marks, but one College student omitted the question. Question 2b requires students toapply Matrix Methods to a system of oscillating particles. There were omissions by the

College students that affected the average, and College students made concept errors where the main stream students made careless errors. The College students made many concept and careless errors in Question 2c, which is an application of Centres of Gravity, with only one of them getting it correct. The main stream students made careless errors, but five of them got full marks and four of them omitted the question. Question 2 as a whole was handled better by the main stream students.

Question 3 was handled better by the College students. The only errors made by them were careless ones, whereas a few of the main stream students made concept errors and many made careless errors. This question consisted of a two point boundary value question, a steady state solution and a problem that requires the separation of variables and is almost exactly like ones given as examples in lectures.

1997	Q1 [40]	Q2 [40]	Q3 [40]	Total [120]	Total %
College (7)	22.28	20.71	24.14	67.14	55.95
Main stream (28)	20.78	21.64	25.96	68.39	56.99

Table 4.15 Mean marks for questions in the 1997 APPM280 examination. Marks given out of the total for the question.

There are very small differences in the averages in all the questions.

Question 1a which was a question that students had not seen before, required the solution of a second order Differential Equation. Most of the students struggled with it, the full range of errors are present in the answers, and no one got full marks. Question 1b, covering small oscillations of a body, was handled well by almost all students except for the sub-group headed by student 96/7E, which got the lowest mark for the examination, and a few other students who made concept errors or omitted the question. The average for the College students was affected by one student who omitted Question 1a, and made a concept error in Question 1b. Without this mark, the College average is 25.3 which is materially greater than the main stream average.

Question 2a and 2b were answered well by all students. They are respectively a Centres of Gravity example similar to one in the notes and a Matrix Methods for systems of oscillating particles example which was given as a tutorial question. Question 2c is the vector-matrix question that appeared in the 1996 examination paper and in several other past papers prior to 1995. The students were aware that it is a likely examination question. There were many concept errors and omissions in 2c. Two of the College students omitted the question, two got 0 because of concept errors and the other three made careless errors. Eight main stream students omitted the question and most of the others made concept errors. One student got full marks. For the question as a whole, the College and mainstream students had averages that are very close.

Question 3a, a two point boundary value question, was answered well by most students, as were the first three parts of Question 3b, a second order differential equation, the main errors being careless or leaving the question incomplete. These questions appear in all three APPM280 question papers. All the students made errors in the last part of Question 3b, which is similar to a tutorial question; all the errors except omission were made. Question 3c was a disaster for all the students. It was an unseen question which required the students to apply the answer from the previous question to a new set of equations. Many of them omitted it and nearly everyone else made concept errors. Question 3d, a steady state question, was answered very well by all except two College students who omitted it and a student in the last sub-group who made a concept error. All other errors were careless errors. On the question as a whole the main stream students had the higher average.

4.5.5 Summary

There are appreciable differences in marks in the following cases :

1995	small oscillations and centres of gravity	main stream better than College
1996	simple harmonic motion; moments of inertia	main stream better than College
1996	two point boundary value problems	College better than mainstream

Table 4.16 **Sections of the APPM280 syllabus in which there are appreciable differences in mean marks between the College and main stream groups.**

There seem to be no patterns in the way the students answered the questions when the topics that the questions are based on are considered. When differences are sought by considering the bookwork versus the application categories of questions, the College students are seen to be equivalent to the main stream students. (The table showing this result is in Appendix 8.)

4.6 Research Focus 5 : Answers to Examination Questions

4.6.1 94/95 Students

Table 4.17 shows the following results :

APPM182 : As a group, the College students leave more questions incomplete than the main stream students and the mainstream students seem more likely to make concept errors than the College students, but otherwise there is very little difference in the other categories of answers between the groups.

APPM182	Group	correct	careless	incomplete	concept	omitted
6	College	7	19	7	12	1
36	main	43	118	33	86	6
calibrated	main	7.17	19.67	5.5	14.33	1
APPM280						
6	College	36	10	9	29	12
38	main	277	84	80	136	30
calibrated	main	43.7	13.26	12.63	21.47	4.74

Table 4.17 Number of students giving each type of answer in the 1994 APPM182 and 1995 APPM280 examinations.

APPM280 : As a group, the College students get fewer questions correct, make more concept errors and omit a lot more questions but make fewer careless errors and leave fewer questions incomplete than the main stream students.

Comparing first and second year, the group of College students has fallen behind in the correct, concept and omitted categories, but made gains in the careless and incomplete categories.

4.6.2 95/96 Students

Table 4.18 shows the following results :

APPM182 : The College students leave fewer questions incomplete, but in all other categories are worse than the main stream students.

APPM280 : The College students get more questions correct, make fewer careless errors, and leave fewer questions incomplete, but the main stream students make fewer concept errors and omit fewer questions.

APPM182	group	correct	careless	incomplete	concept	omitted
5	College	5	19	1	17	3
29	main	41	76	15	95	13
calibrated	main	7.07	13.10	2.59	16.38	2.24
APPM280						
5	College	39	16	1	14	10
28	main	199	128	21	66	33
calibrated	main	35.54	22.86	3.75	11.79	5.89

Table 4.18 **Number of students giving each type of answer in the 1995 APPM182 and 1996 APPM280 examinations.**

Comparing first and second year, the College students maintained their supremacy in the incomplete category and made gains in the correct and careless categories. They were behind the mainstream students in the concept and omitted categories for both years.

4.6.3 *96/97* Students

Table 4.19 shows the following results :

APPM182 : The College students get fewer correct answers, make more careless errors, and leave more incomplete, but make fewer concept errors and omit fewer questions than the main stream students.

APPM280 : The College students get fewer correct, make more careless errors, leave more incomplete and omit more questions, but make fewer concept errors than the main stream students.

APPM182	group	correct	careless	incomplete	concept	omitted
7	College	30	27	12	14	0
37	main	169	136	42	80	17
calibrated	main	31.97	25.73	7.95	15.14	3.22
APPM280						
7	College	11	17	6	22	7
28	main	58	56	18	102	17
calibrated	main	14.5	14	4.5	25.5	4.25

Table 4.19 Number of students giving each type of answer in the 1996 APPM182 and 1997 APPM280 examinations.

Comparing first and second year, the College students maintained their supremacy in the concept category, but fell behind in the omitted category. They remained behind in the correct and careless categories.

Chapter 5 : Discussion

5.1 Introduction

The College students had matric ratings that were lower than the minimum requirements for automatic entry in the Engineering Faculty or had mathematics marks that were below the required symbol. They were regarded as being under-prepared for university, but were being given a chance because their entrance tests indicated a potential to succeed at university.

Rutherford and Matlou (1996) describe the majority of College students as "the first in their family to attend university" which means they are without a support structure, such as family and friends, that understands the experiences they have at university. They are also "unfamiliar with the large university campus" (ibid) and often get lost on campus, especially at the beginning of their first year. Furthermore, many College students are "unfamiliar with a larger city environment" (ibid) and are often prey to criminals because they not very 'streetwise'. These factors make College students feel insecure which hampers their efforts to do their best right from the beginning.

Being English second language speakers severely hampers College students' understanding of lectures and instructions. Not speaking English as a first language is one of the causes of the low retention rates among Hispanics in America (Smith 1995). The College students seem to be able to overcome this handicap by the end of their second year, but it is very noticeable at the beginning of their first year in the College.

College students are often "not aware of student services on campus" (Rutherford and Matlou 1996) so that they often don't know where to get help if they are sick or in need of financial assistance or counselling. They are also lacking in understanding about the quantity and quality of work required at university. They often fall behind in their work and become upset and angry when their work is not up to standard. Sometimes they choose courses which do not suit them, and have vague ideas about the purpose of their studies, causing a lack of motivation. The College engineering students had chosen to be engineers and most of them had that as an intrinsic motivation. There were some, however, who realised that they did not want to be engineers and lost their motivation, did not work hard enough and failed. Others maintained their motivation but changed faculties at the end of their first or second year in the College.

Hsiao (1992) pointed out that many students do not manage their time efficiently and this is undoubtedly a contributory cause when students fail, and may well be one of the reasons why College students are usually in the middle range of a main stream class, rather than in the top range.

The Engineering Sciences class in the College was always small compared to the main stream class. The first year College classes corresponding to the years under consideration were respectively 60, 63 and 72 in number. The second year classes reduced to 49, 43 and 48. The classes had tutors that were well prepared and enthusiastic about helping under-prepared students to cope. There was usually at least one tutor for every twenty students. These factors enabled the lecturers and tutors to get to know the students and for the students to feel free to ask questions. The students also had access to support structures (such as counselling) from the core staff of the College that were not available to the main stream students.

The first year main stream classes were very large (300 +), and even splitting the class into three smaller classes (~100) each with their own lecturer meant that the classes were still large. The traditional lecturing style used by the lecturers meant that there were few opportunities for the lecturers to get to know the students and the lecturers were not available very often for consultation due to heavy work loads. The number of tutors required in order to have one tutor per 20 students mitigated against being able to choose capable and committed people and often there were not enough potential tutors available to be able to maintain that ratio. The standard of tutoring was thus not high in most years. The size of the classes, the lecturing style and the poor tutoring meant that main stream students were not able to get help easily.

The second year main stream classes were about 100 students, which is about the same size as the class assigned to one lecturer in first year. The tutors had to be selected carefully because they needed to be competent at a higher level of mathematics than was required for first year tutoring.

5.2 Research Focus 1 : Teaching Methods

5.2.1 First and Second Year College and First Year Main Stream

The College students had several advantages over the main stream students. The small classes and the presence of tutors at all teaching sessions meant that they were able to get individual attention easily. Working in groups enabled them to talk about mechanics. They learned to articulate concepts in their own words and to express themselves in English. They were willing to ask questions of each other and the tutors. Those who felt they understood the questions were able to teach their peers, and in so doing enhanced their own understanding. These advantages stood them in good stead in enabling them to meet the challenge of passing the main stream examination.

Students felt pressurised for time in their second year of the College. The main stream courses that they attended put them under a lot of stress. The mechanics course counted either 20% or 30% or 50% towards their Engineering Sciences mark (depending on the branch they were registered in - see Appendix 6). This had a negative effect on their attitude. They tended to regard the course as unimportant and of a low priority. The regular testing and hand-in assignments were used to counter-act the negative attitude which led to the students not wanting to keep up with their work.

The gradual move in the second year of College mechanics from tutorial time mixed with lecture time to the lectures and tutorials being separate was to help the students become accustomed to the way they would be taught in the mainstream, but the teaching staff were aware that extra input (compared to mainstream) was necessary in order for the students to cope with the course. The photocopied notes enabled the lecturer to cover the material in the notes and expand on it without subjecting the students to 45 minute "stenography lessons" (Hauser *et al* 1995).

The methods used appeared to make the College students self-confident and willing to tackle difficult problems.

The main stream students were taught in a traditional "chalk and talk" manner. They had to be coerced into coming to tutorials. The lecturers were keen to see them succeed, but the size of the class and the way the teaching was done (both in the lectures and in the tutorials) mitigated against them. The lecturers feel that students find mechanics difficult, but they cannot identify what it is that makes the students struggle, and thus cannot give any reasons or explanations for the low pass rates. This lack of understanding on the lecturers' part possibly accounts for the fact that they kept to the same lecturing technique in spite of poor pass rates. Astin (1991) recommends that results are used as feedback to enlighten and inform teaching practise. It is clear that this was not occurring.

Main stream students had only two class tests in which to gain an acceptable class mark, and many of the students in the class were struggling with many of the same disadvantages as the College students because they came from similar backgrounds. There were no conscious attempts to assist the students from disadvantaged backgrounds. The tutors were often under-prepared and the lecturers were difficult to consult with because of their heavy work loads. The main stream students had many obstacles to overcome on their own so it is not surprising that the pass rates were low.

In 1996 an attempt was made to improve the pass rate by completing the course in the usual one semester and then having fewer lectures per week for half a semester during which revision in the form of extra tutorial questions and past examination papers was done. The College students were able to attend the extra preparation as well. The examination was held in September, during the first week of the last quarter. It appears that the longer time spent by students on revision and the addition of formal examination preparation did result in a much improved pass rate.

5.2.2 The Second Year Main Stream Course

The course was given in the second semester of the year. The College students had had a semester to acclimatise to being in the mainstream and had learned what to expect in lectures.

The course was lectured by Mr. Buric in 1995 and Prof. Block in 1996 and 1997. The content of the course did not change with the change in lecturer, but there is a difference in the way the questions in the examination paper are set. Prof. Block followed the pattern used by Mr. Buric, but introduced some interesting practical applications as questions.

The teaching pattern was the same in the second year course as in the main stream first year course, with the calibre of tutor being better. There was an ongoing preparation for the examination in the sense that students were told that certain bookwork and examples were very likely or even certain to appear in the examination.

5.3 Research Focus 2 : Pass Rates and Distribution of Final Marks

5.3.1 Pass Rates

The pass rate of the APPM182 College students in 1994 was lower than the pass rate of the corresponding main stream students. There is no clear reason for this, but it could simply be that that cohort was a weak group of students. The APPM182 College pass rates for 1995 and 1996 are very similar to the main stream ones, but the 1996 pass rates are substantially higher than the previous years, due to the extra time spent preparing for the examination.

The APPM280 pass rates are affected by the small size of the College group in each year (6 in 1995, 5 in 1996 and 7 in 1997). One student represents a high percentage of the whole group. Out of the 18 students there were only 3 failures. There is a drop in the main stream pass rate between 1995 and 1996, which could be due to the change in lecturer and the slight change in the style of the examination questions. Students use past examination papers as a guideline to what they actually have to do in order to pass (Rowntree 1997).

5.3.2 The Distribution of the Final Marks

In the APPM182 courses there were no College students who got below 20% or above 90%, but there were a few main stream students in each year who did. The College students started off being more under-prepared than the main stream students. Using matric symbols as admission criteria implies that they can predict that students who are admitted to a course have a reasonable chance of success. The College students' symbols implied that they had at best a very small chance of success at university. The College experience has enabled many of them to change from inadequate to adequate students after two years of careful teaching and support. There are no very high achievers, but there are no totally hopeless cases either. Some students did not succeed even after two years, but those students who still wanted to do engineering went to Technikons or to other universities where they were able to make a fresh start in first year mainstream at those institutions.

The tables of the distributions of final marks for APPM280 show that the College students were firmly placed in the 50% to 79% range. They were passing in the adequate to good range. It is very clear that the College students became equivalent to the mass of main stream students, but they started out as students who would normally have been refused the opportunity to attend university.

5.4 Research Focus 3 :The progress of the College Students

Table 4.9 (p. 34) shows that all of the College students except three passed at the end of APPM280. Smith (1995) reports a drop in the retention rate between first year and second year for under represented minority students in America during 1985 - 91. The College students have similar characteristics to the minority students in America, yet their retention rate at the end of second year main stream is high (83%), which is the same or better than at the end of the College years. The College experience has not resulted in a drop in retention in the Applied Mathematics course.

5.5 Research Focus 4 : Comparing Average marks for Questions in the Examinations

The most remarkable thing to emerge from the analysis of the data (both APPM182 and APPM280) is that the College students are really no different to the main stream students:

- There are no consistent patterns of College students doing any particular topic from the syllabus better or worse than the main stream students

- There is no difference in the average marks for bookwork (i.e. rote learning) between the two groups

- There is no difference in the average marks for application type questions (i.e. problem solving) between the two groups

- Where College students answered a question well, so did the main stream students

- Where College students answered a question badly, so did the main stream students.

5.6 Research Focus 5 : Answers to Examination Questions

Table 5.1 summarises the change in status (with respect to the kinds of answers given in the examinations) of the College students compared to the main stream students in the APPM182 year compared to the APPM280 year in the different answer categories. The arrows indicate the transition from APPM182 to APPM280. For instance, in 1994 the College students had the same number of correct answers as the main stream students, but in 1995 they had fewer correct answers than the main stream students.

Years	94/95	95/96	96/97
correct	same→ fewer	fewer → more	fewer → fewer
careless	same → fewer	more → fewer	more → more
concept	fewer → more	more → more	fewer → fewer
incomplete	more → fewer	fewer → fewer	more → more
omitted	same → more	more → more	fewer → more

Table 5.1 Status changes of College students in the answer categories.

The only category where the College students were consistently worse in APPM280 than they were in APPM182 (compared to the main stream students) is the "omitted" category. Combining the "incomplete" and "omitted" categories also shows the College students as being consistently worse than the main stream at the end of APPM280. This may mean that the College students have a problem with time management. Perhaps they spent time thinking about questions they found difficult and then found they did not have time to attempt some of the questions.

In questions which required a diagram to be drawn from a written description, both main stream and College students made many mistakes and were thus not able to answer the rest of the question properly. This type of question is at the 'analysis' level in Bloom's Taxonomy (Bloom 1956) and there seems to be a lack of these skills in all students in this study.

The results from the data in this section emphasise again that there is no consistent pattern of College students being better or worse than main stream students. The College students do not make consistently more concept errors, which one might expect given that the College students started from a theoretically worse academic base line than the main stream students did. College students were likewise no more careless than the main stream students were.

5.7 Conclusions

The College students started from a more disadvantaged position than the main stream students, but attained the same status as the main stream students in the Applied Mathematics courses under consideration by the end of their second year in the College. They maintained or improved their standing by the end of the second year main stream course.

There are no topics in the syllibi where the College students stand out as markedly better than the main stream students, neither are there any where they markedly worse.

The College students made errors in their answers which were mostly in the same proportions as the main stream students. The only area where the College students have a consistently lower achievement than the main stream students is in the categories that measure where answers are not completed, possibly indicating time management problems in examinations.

The main difference between the College students and the main stream students lies in the way they were taught in the APPM182 course. The College experience enabled students not normally considered capable of coping at university to become equivalent to the average main stream student in the Applied Mathematics courses under consideration.

The College of Science made a significant contribution in assisting the disadvantaged students who registered for Engineering in the College to achieve beyond the expectations implied by their matriculation results.

Appendix 1 : Calculation of Matric Rating

Matric symbol	Rating*			
	Higher Grade	Standard Grade	English (1st or 2nd Language)HG	Maths HG
A	6	4	2	2
B	5	3	2	2
C	4	2	2	2
D	3	1	-	-
E	2	0	-	-
F	1	-	-	-
G	0	-	-	-

* For each of English (1st or 2nd Language) HG and Mathematics HG - **add 2 points to your overall score** if an A, B or C symbol is obtained. For example, if you get an 'A' for Maths HG, you get 6 points plus another 2 points. A 'C' symbol for English HG counts 4 points plus an additional 2 points.

To be admitted automatically the requirements are :

	Rating	Maths HG	Physical Science HG	English HG
Aeronautical	24	C	D	D
Chemical	24	C	D	D
Civil	24	C	D	D
Electrical	26	C	D	D
Industrial	24	C	D	D
Mechanical	24	C	D	D
Metallurgy	21	C	D	D
Mining	18	D	D	D

Appendix 2 : Course Content of College Courses

Physical Sciences

PHYS122 : The thermal, mechanical, electrical and optical properties of matter were treated from a physical and chemical perspective. Newtonian mechanics was touched on in a qualitative way in the first year.

PHYS127 : Elasticity; hydrostatics; hydrodynamics; waves; surface tension; electricity; magnetism; modern physics.

Mathematical Sciences

MATH122 : Relations and functions, the remainder theorem, the logarithmic and exponential functions, complex numbers, trigonometric functions, Induction. The binomial theorem. Limits and continuity, the derivative and its applications. Vectors.

MATH127 : Integration and its applications, hyperbolic functions, Vectors in R^2 and R^3. Linear equations and matrix algebra. Sequences and series. Differential equations, partial derivatives. Conic sections.

Branch-specific Courses for Engineering Sciences IB

CHEN123 Engineering Sciences IB (Chemical) :

Professional Studies : report writing; introduction to computers, word processing and database software packages, simple

Pascal programming.

CHEM124 : kinetics, a more detailed study of thermodynamics and kinetics, an introduction to organic chemistry, a quantum approach to atomic and molecular structure and aspects of inorganic and electrochemistry.

CHEN102 : (Chemical) Introduction to Process and Materials Engineering : Discussion of some common industrial processes in chemical and metallurgical engineering. Properties and applications of various engineering materials. Elementary process design calculations. Units and dimensions; stoichiometry; mass balances for continuous steady-state processes.

Mechanics : Vector product; systems of coplanar forces; centres of gravity; revision.

CIVN123 Engineering Sciences IB (Civil):

Professional Studies : report writing; introduction to computers, word processing and database software packages, simple Pascal programming.

MECN103 : Advanced Graphics: perspective drawing. Advanced intersections. Revolution. Machining processes. Second auxiliary. Applications of descriptive geometry. An exposure to CAD and its application to the foregoing.Civil design: Introduction to general engineering design; introduction to civil engineering design; introduction to civil engineering; case studies; projects; site visits.

Mechanics : Vector product; systems of coplanar forces; centres of gravity; revision. APPM183: Relative velocity; shearing force and bending moment; moments of inertia; rotation of a rigid body.

ELEN123 Engineering Sciences IB (Electrical)

ELEN100 : Electrical Circuits

ELEN101 : Engineering design (Electrical)

Mechanics : Vector product; systems of coplanar forces; centres of gravity; revision. APPM183: Relative velocity; shearing force and bending moment; moments of inertia; rotation of a rigid body.

Professional Studies : report writing; introduction to computers, word processing and database software packages, simple Pascal programming.

MECN123 : Engineering Sciences IB (Mechanical)

Professional Studies : report writing; introduction to computers, word processing and database software packages, simple Pascal programming.

MECN111: Advanced Graphics: perspective drawing. Advanced intersections. Revolution. Machining processes. Second auxiliary. Applications of descriptive geometry. An exposure to CAD and its application to the foregoing. Mechanical design.

MECN115: Introduction to Mechanical Engineering

Mechanics : Vector product; systems of coplanar forces; centres of gravity; revision. APPM183: Relative velocity; shearing force and bending moment; moments of inertia; rotation of a rigid body.

METN123 Engineering Sciences IB (Me allurgy)

Professional Studies : report writing; introduction to computers, word processing and database software packages, simple Pascal programming.

Mechanics : Vector product; systems of coplanar forces; centres of gravity; revision.

CHEM124: kinetics, a more detailed study of thermodynamics and kinetics, an introduction to organic chemistry, a quantum approach to atomic and molecular structure and aspects of inorganic and electrochemistry.

METN103 : Introduction to process and materials engineering.

MINN123 Engineering Sciences IB (Mining)

Professional Studies : report writing; introduction to computers, word processing and database software packages, simple Pascal programming.

MINN103 : Mining graphics and design (1996). (MECN111 alone in 1994 and MECN111 and MINN103 in1995)

Mechanics : Vector product; systems of coplanar forces; centres of gravity;

revision.

MINN102 : Introduction to mining.

Appendix 3 : Courses Taken by First Year Main Stream Students

Chemical

APPM182	Applied Mathematics IA
CHEM101	Chemistry I (Major)
CHEN102	Introduction to Process and Materials Engineering
MATH180	Mathematics I
MECN101	Engineering Graphics
PHYS180	Physics I

Civil

APPM183	Applied Mathematics IB
CHEM180	Chemistry I (Auxillary)
MATH180	Mathematics I
MECN103	Engineering Graphics and Design
PHYS180	Physics I

Electrical

APPM183	Applied Mathematics IB
ELEN100	Electrical Circuits
ELEN101	Engineering Design (Electrical)
MATH180	Mathematics I
MECN113	Engineering Graphics (Electrical)
PHYS180	Physics I

Mechanical

APPM183	Applied Mathematics IB
CHEM181	Chemistry I (Auxiliary)
MATH180	Mathematics I
MECN111	Engineering Graphics and Design
MECN115	Introduction to Mechanical Engineering
PHYS180	Physics I

Metallurgy

APPM182	Applied Mathematics IA
CHEM101	Chemistry I (Major)
MATH180	Mathematics I
MECN101	Engineering Graphics
METN103	Introduction to Process and Materials Engineering
PHYS180	Physics I

Mining

APPM182	Applied Mathematics IA
CHEM180	Chemistry I (Auxiliary)
MATH180	Mathematics I
MECN111	Engineering Design (up to 1994)
MECN113	Engineering Graphics
MINN102	Introduction to Mining
MINN103	Mining Graphics and Design (from 1995)
PHYS180	Physics I
MINN101	Practical Training (Mining) (from 1995)

Appendix 4 : Courses Taken by Second Year Students

Chemical

APPPM280	Applied Mathematics IIA
CHEM280	Chemistry II
CHEN203	Materials and Corrosion
CHEN205	Engineering Concepts (Chemical)
CHEN207	Process Engineering
ELEN201	Engineering Applied Computing
MATH280	Mathematics II

Civil

APPM280	Applied Mathematics IIA
CIVN204	Earth Materials and Processes
MATH280	Mathematics II
CIVN206	Transportation Engineering I
CIVN207	Construction and Development
CIVN219	Materials and Structures
ELEN201	Engineering Applied Computing
MINN250	Surveying for Engineers
CIVN201	Practical Training (Civil)
CIVN202	Vacation Work I (Civil)

Electrical

ELEN205	Linear Systems
ELEN214	Engineering Applied Computing

ELEN222	Electric Power I
ELEN224	Electronics I
ELEN226	Microprocessor Engineering A
MATH280	Mathematics II
PHYS282	Physics II (Electrical)
ELEN206	Vacation Work I

Mechanical

ELEN201	Engineering Applied Computing
ELEN207	Electrical Engineering
MATH280	Mathematics II
MECN208	Fluid Mechanics I
MECN211	Applied Mechanics II
MECN226	Mechanical Engineering Design I
MECN247	Mechanical Engineering Laboratory I
MECN248	Thermodynamics I
METN216	Materials Engineering
MECN210	Vacation Work I

Metallurgy

APPM280	Applied Mathematics IIA
CHEM280	Chemistry II
MATH280	Mathematics II
METN204	Materials and Corrosion
METN205	Engineering Concepts (Metallurgy)
METN207	Process Engineering
METN201	Practical Training (Metallurgy and Materials Engineering)
METN202	Vacation Work I

Mining

APPM280	Applied Mathematics IIA
ELEN207	Electrical Engineering
MATH280	Mathematics II
GEOL104	Geology I
MINN200	Computer Applications in Mining
MINN205	Health, Safety and the Mining Environment
MINN221	Mining A
MINN250	Surveying for Engineers
MINN202	Practical Workshop Training (Mining)
MINN203	Vacation Work I

Appendix 5 : Course Codes for Mechanics

The course codes used by the College are confusing : the College referred to the course as MECN122A(Mechanics) and MECN122B(Mechanics) to begin with, but then changed to MECN122(Mechanics) and MECN123(Mechanics). The Engineering Faculty registered the students according to their branches, so the Examinations Office referred to the courses as CIVN122, CHEN122, ELEN122, MECN122, METN122 AND MINN122 in the first year and the corresponding 123 courses in the second year.

The main stream courses were APPM182 and APPM183, also depending on which branch the students were registered in.

Appendix 6 : Subject Weightings for Engineering Sciences

1994	College Mech	APPM 183	CHEM 124	CHEN 102	MECN 103	ELEN 100	ELEN 101	MECN 111	MECN 115	METN 103	MINN 102
CHEN123	20		40	40							
CIVN123	20	30			50						
ELEN123	20	30				40	10				
MECN123	20	30						40	10		
METN123	20		40	40							
MINN123	30							50			20

1995	College Mech	APPM 183	CHEM 124	CHEN 102	ELEN 100	ELEN 101	MECN 111	MECN 115	METN 103	MINN 102	MINN 103
CHEN123	20		40	40							
CIVN123	20	30					50				
ELEN123	20	30			40	10					
MECN123	20	30					40	10			
METN123	20		40	40							
MINN123	30						30			10	30

1996	College Mech	APPM 183	CHEM 124	CHEN 102	ELEN 100	ELEN 101	MECN 101	MECN 111	MECN 115	METN 103	MINN 102	MINN 103
CHEN123	20		40	40								
CIVN123	20	30					50					
ELEN123	20	30			40	10						
MECN123	20	30						40	10			
METN123	20		40	40								
MINN123	50										15	35

Appendix 7 : Examination Papers

The APPM182 examinations were two hours long.

APPM182 : JUNE 1994

QUESTION 1

(a) Define *power* and state the relation between tractive effort, power and velocity for a moving vehicle. [2]

(b) A car's engine develops maximum useful power of 49 kW. Its mass is 1500kg and its maximum speed on a level road is 180km/h. Assume that the resistance to its motion is proportional to its speed. Find, in km/h,

(i) the maximum speed at which it can move *up* a slope of 1 in 10,

(ii) the maximum speed at which it can move *down* a slope of 1 in 10.

[15]

Does the speed you have found in part (ii) seem unrealistically high? If so, give a brief explanation of your result. [2]

If the car is moving *up* the slope and using full power, find its acceleration at the instant when its velocity is 36km/h. [6]

QUESTION 2

(a) For the direct impact of two spheres, state

(i) The Law of Conservation of Momentum [5]

(ii) Newton's Law of Impact [5]

(b) Two spheres each of mass 2kg collide directly. Their initial velocities are u and 12 m/s and the coefficient of restitution for the collision is $e = ⅔$. During impact 10 Joules of kinetic energy are lost. Find u and the final velocities of the spheres. Explain carefully the two answers obtained. [15]

QUESTION 3

(a) A particle moves in a circle of radius r with a constant angular velocity ω. Determine the magnitude and direction of its acceleration. [9]

(b) The planet Mars has two moons Phobos and Deimos which move approximately in circles about the centre of Mars. Phobos moves in a circle of radius 9300km and has a period of revolution about Mars of 0.307 days. Deimos moves in a circle of radius 23500km. What is the period of orbit of Deimos? (Neglect the gravitational attraction between the moons)

[16]

QUESTION 4

(a) State a set of conditions for the equilibrium of a system of coplanar forces acting on a rigid body. [9]

(b) A uniform beam AB of length 4 metres and weight W is freely hinged to a vertical wall at A. It is kept in a horizontal position by a cable attached to B and to point C on the wall above A, such that $A\hat{C}B = 30^0$. A man of weight $\frac{W}{2}$ stands on the beam at D where $AD = x$ metres. If the tension in the cable equals the weight of the beam, find

(i) the reaction at the hinge,

(ii) the value of x.

[20]

QUESTION 1

The electric motor of a locomotive of mass m produces constant useful power P. The locomotive starts from rest at time $t = 0$ on a horizontal track. Neglecting resistance to motion, use energy considerations to find an expression for the velocity v of the locomotive at time t. Hence find its acceleration at time t and comment on your result for the acceleration in relation to the tractive effort at the start of the motion.

[13]

QUESTION 2

(a) (i) State without proof the Principle of Conservation of Momentum.

(ii) State without proof the Principle of Conservation of Mechanical Energy.

[6]

(b) A bullet of mass m is fired with velocity v_1 into a small block of hard wood of mass M suspended at rest from a fixed point by an inextensible string of length L. The bullet becomes embedded in the wood and the block containing the bullet then swings without spinning through an angle θ_1 before coming instantaneously to rest.

The experiment is repeated with an identical bullet, an identical block of wood and an identical string, but this time the bullet has velocity v_2 and the string swings through an angle θ_2 before coming to rest.

Find the ratio $\frac{v_1}{v_2}$ in terms of $\sin\left(\frac{\theta_1}{2}\right)$ and $\sin\left(\frac{\theta_2}{2}\right)$. [Hint: $\cos 2x = 1 - 2\sin^2 x$]

[16]

QUESTION 3

Five spheres A, B, C, D, E of the same diameter lie in a straight line at rest, in that order, on a smooth horizontal plane, their masses being 1, 2, 4, 8, 16 kg respectively. A is projected towards B with a speed of 80 m/s. If for each impact $e = ½$, and if A impinges on B, then B on C, and so on, find the speed of E immediately after it has undergone direct impact with D.

[15]

QUESTION 4

a) A point moves in a circle of radius r with constant angular velocity ω. Find the magnitude and direction of its acceleration. [10]

b) A particle is projected with velocity u from the lowest point inside a smooth circular hoop of radius r lying in a vertical plane. Find the LEAST value of u for the particle to just reach the highest point.

[15]

QUESTION 5.

a) *State* the theorem of moments and *prove* this theorem for the case of two forces F and G whose lines of action intersect.

[7]

b) A uniform beam AB of weight W and length 2a is freely hinged to a horizontal floor at A. It is supported by a force F at B so that it makes an upward angle arctan (¾) with the floor. Find F and the reaction at the hinge

(i) if F acts VERTICALLY;

(ii) if F is PERPENDICULAR to the rod.

[18]

QUESTION 6 : FOR EXTRA MARKS:

Consider an isolated system of two interacting particles. Show that the total momentum of the system is conserved, stating clearly any assumptions you make.

[6]

QUESTION 1

(a) State Newton's Law of Universal Gravitation. [4]

(b) Let E and M denote the masses of the earth and moon respectively and R the distance between their centres. P is a point on the line through the centres of the earth and moon, at a distance r from the centre of the earth. The gravitational attractions of the earth and moon on a particle at P are equal in magnitude. Given $E = 81M$, find r in terms of R and give a physical interpretation of the results you obtain.

[18]

QUESTION 2

(a) A block of weight W is moving up a rough inclined plane, angle of inclination α, coefficient of friction μ. There is no driving force on the block. Draw a clear diagram of the forces acting on the block and by resolving them into components along and perpendicular to the plane, find the acceleration of the block.

[6]

(b) The same block comes to rest on the slope and then starts to slide back down. If $\mu = \tan \lambda$ where λ is the angle of friction, what can we say about the relationship between λ and α the angle of inclination? Draw a clear diagram of the forces acting on the block in this instance. Resolve them into components, along and perpendicular to the plane, and hence find the acceleration of the block.

[6]

(c) A block of weight 200N is projected - rough slope, angle of inclination 45^0, coefficient of friction ½, with an initial velocity of 5m/s. Find the distance it travels up the slope before coming to rest. Will it slide back down? If so, find its velocity when it returns to its starting point.

[12]

QUESTION 3

(a) PROVE the work-energy relation.

[8]

(b) A truck of mass 3000kg, whose engine is developing 20kW is moving on the level at a steady speed of 60km/h. Determine the resistance to its motion. If the truck comes to a hilly road AB, find by energy considerations, the road distance from A to B where B is 25m lower than A, and the time to cover AB is 1 minute. Assume the resistence and power of the engine to be as before, and the speed at B is 90km/h.

[14]

QUESTION 4

(a) A particle is projected with speed V at angle α to the horizontal. Write down, WITHOUT PROOF, the equations for its horizontal and vertical components of displacement t seconds after projection. HENCE, derive the equation of the path in terms of $\tan\alpha$ where α is the angle of projection.

[8]

(b) A stone is thrown from the top of a tower 30m high at 49m/s. It strikes the horizontal ground at the foot of the tower 70m from the foot. Find

(i) the possible angles of projection

(ii) the time taken to reach the ground

[13]

(c) Use ENERGY considerations to determine the speed with which it hits the ground.

[5]

QUESTION 5

(a) Write down the two equations which govern the direct impact of two spheres, explaining the symbols by means of a suitable diagram.

[5]

(b) A sphere of mass 2 kg moving at 12 m/s collides directly with a sphere of mass 1 kg moving at U m/s. If the coefficient of restitution is ½ and 81 J of energy are lost in the impact, find

(i) the possible values of U

(ii) the final velocity of each sphere

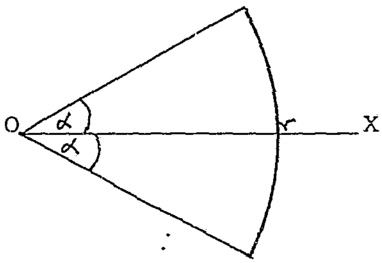
[21]

The APPM280 examinations were three hours long.

APPM280 : November 1995

QUESTION 1

(a) A uniform thin rod is bent into the form of a circular arc of radius r, subtending an angle 2α (radians) at its centre.

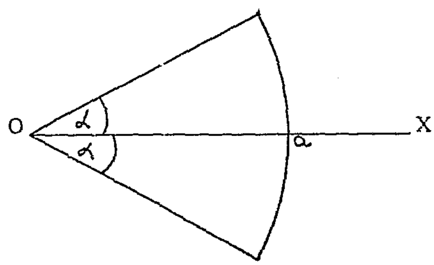


Show that the x-coordinate of its C.G. is given by

$$\bar{x} = \frac{r\sin\alpha}{\alpha}$$

[7]

(b) A uniform lamina is in the form of a sector of a circle of radius $\underline{a}$, subtending an angle of 2α (radians) at its centre.

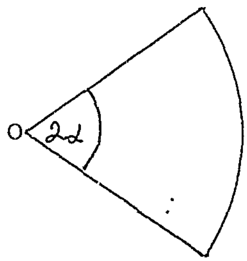


Using the result of (a), show that the x-coordinate of its C.G. is given by

$$\bar{x} = \frac{2a\sin\alpha}{3\alpha}$$

[8]

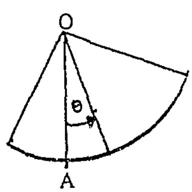
(c) Consider again the lamina of mass m (say) described in (b).



Deduce the M.I. of this lamina through O and perpendicular to the plane of the lamina, given that the M.I. of a uniform circular lamina of mass M and radius $\underline{a}$ about the axis through its centre and perpendicular to its plane is $\frac{1}{2}Ma^2$.

[4]

(d) The lamina of mass m described in (b) now hangs in a vertical plane and performs small oscillations about a fixed horizontal axis through O as shown.



(OA is vertical)

Taking counterclockwise as positive, write down the equation of motion and hence find the period of the oscillations.

[8]

QUESTION 2.

(a) Explain briefly what is meant by the characteristic equation, eigenvalues and eigenvectors of a matrix. [4]

(b) State the Cayley-Hamilton theorem [2]

(c) Use the Cayley-Hamilton theorem to find the inverse of the matrix

$$\begin{bmatrix} 7 & 4 \\ 3 & 6 \end{bmatrix}$$

[6]

(d) Define a matrix T such that for some $n \times n$ matrix A with distinct eigenvalues λ_r, $r = 1,2,\ldots\ldots, n$,

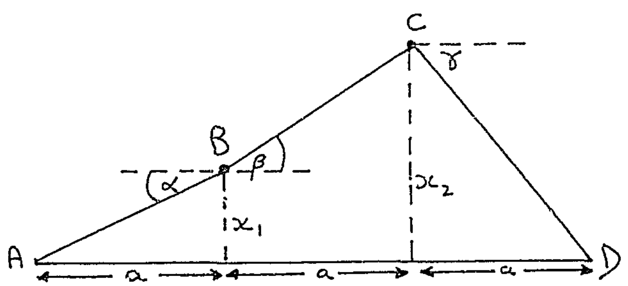
$$T^{\prime}AT = D(\lambda)$$

where D is a diagonal matrix with elements corresponding to the eigenvalues. Then demonstrate that this is true.

[6]

QUESTION 3

Two particles of mass m are connected by three identical light elastic strings.



The end points A and D of the strings are fixed and the system rests on a smooth horizontal plane. When in the equilibrium position the stretched length of each string is $\underline{a}$ and the tension in each string is T. The particles now undergo *small* transverse oscillations with displacements x_1 and x_2, as shown, which are first order small quantities.

(i) Show briefly that the increase in the length of the string AB due to the motion is a second order small quantity. What, therefore, is the tension in the string while the string is oscillating?

[3]

(ii) Carefully write down the equation of motion for each particle, using the notation in the diagram and letting $\frac{T}{ma} = \omega^2$.

[6]

(iii) Hence write the two equations of motion in matrix form

$$\frac{d^2X}{dt^2} = AX$$

Where $X = \begin{matrix} x_1 \\ x_2 \end{matrix}$. Each element of the matrix A should be expressed in terms of ω.

[1]

(iv) Find the *natural frequencies* of the system in terms of ω.

[4]

(v) Determine suitable conditions for the system to oscillate in each of its *normal modes*.

[8]

QUESTION 4.

(a) Consider the TPBVP (two point boundary value problem)

$$\frac{d^2y}{dx^2} + \lambda y = 0 \quad y(0) = 0 \quad y(l) = 0$$

(i) Prove that the solutions are trivial if $\lambda \leq 0$ but are nontrivial provided

$$\lambda = \frac{n^2\pi^2}{l^2} \quad n = 1,2,3....$$

[8]

(ii) Find the corresponding eigenfunctions of this TPBVP.

[2]

(b) A stretched elastic string has its end points fixed at $x = 0$ and $x = l$. The displacement $\psi(x,t)$ of the string when undergoing small transverse oscillations satisfies the equation

$$\frac{\partial^2\psi}{\partial x^2} - \frac{1}{c^2}\frac{\partial^2\psi}{\partial t^2} = 0$$

By separating the variables according to

$$\psi(x,t) = \phi(x)\chi(t)$$

show that

$$\frac{d^2\phi}{dx^2} \Big/ \phi = \frac{1}{c^2}\frac{d^2\chi}{dt^2} \Big/ \chi = -\lambda$$

where λ is a constant.

Hence find the standing-wave solutions $\psi_n(x,t)$ which describe the normal modes of vibration of the string.

Now write down the general solution of the wave equation $\psi(x,t)$ and show what form ths solution takes in the particular case where the string is released from rest at $t = 0$ and with initial profile $\psi(x,0) = f(x)$.

[13]

November 1996 : APPM280

QUESTION 1

(a) State (without proof) the differential equation for Simple Harmonic Motion (SHM).

[2]

(b) Show that a simple pendulum of length L performs SHM of period $2\pi\sqrt{\frac{L}{g}}$ about its equilibrium position provided a certain condition is satisfied. State this condition clearly.

[8]

(c) A simple pendulum of length 1,5 metre swings in air. The pendulum completes 20 oscillations in 49,2 seconds, during which time its angle of swing decreases from 6 degrees to 2 degrees.

(i) Detertmine the *differential equation* describing the motion. [2]

(ii) Prove that $g = 1{,}5\left[\frac{4\pi^2}{T^2} + k^2\right]$ where $k = \frac{h}{2m}$ is the correction due to damping.

[3]

(iii) Explicitly find k and hence g. [4]

(d) A particle moving in a straight line has displacement x at time t where

$$\ddot{x} + 2k\dot{x} + 16x = 40\cos 4t$$

Show that, after sufficient time has passed, the motion becomes Simple Harmonic and find the amplitude and period of the SHM. What happens to the amplitude as $k \to 0$?

[11]

(e) Consider the vector-matrix differential equation

$$\dot{x}(t) = A(t)x(t), \qquad x(t_0) = x_0, \quad x \in \mathbb{R}^n$$

Find an appropriate matrix differential equation for $V(t)$ such that the integral

$$J = \int_{t_0}^{t_f} x^T(t)Q(t)x(t)dt, \quad Q \in \mathbb{R}^{nXn}$$

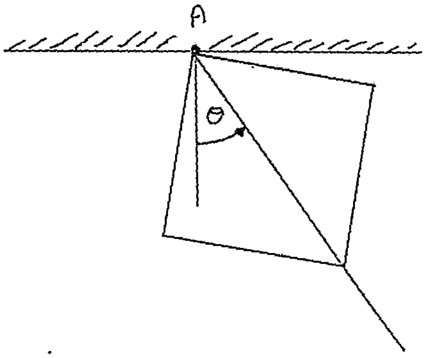
can be written as

$$J = x_0^T V(t_0) x_0$$

[10]

QUESTION 2

(a) A uniform square lamina of side a and mass M is suspended from a frictionless pivot at the vertex A, and undergoes small oscillations about an axis perpendicular to its plane at the pivot. Ignoring air resistance and using $L = I\ddot{\theta}$ prove that for small oscillations the system will perform SHM. Explicitly determine the period T of the SHM in terms of a and g.



[You may assume that the moment of inertia of a uniform square lamina of side a and mass M about an axis through a vertex and perpendicular to the plane of the lamina, is $\frac{2}{3}Ma^2$ and that counterclockwise moments are positive].

[8]

(b) A uniform string of length $4a$ is stretched under tension between two fixed points. Three masses, $5m$, $12m$ and $5m$ (in that order) are attached to the string at points distant a, $2a$ and $3a$ respectively from the left hand end. The masses undergo small transverse oscillations on a smooth horizontal table. The tension in each sector of the string is P.

Let x_1, x_2 and x_3 (in that order) describe the displacements of these respective masses from their equilibrium positions.

(i) Carefully find a matrix A such that $\ddot{X} = AX$.

Each entry of A should be evaluated in terms of ω^2 where $\omega^2 = \dfrac{P}{60ma}$.

[6]

(ii) Prove that two of the eigenvalues of A are $-24\omega^2$ and $-4\omega^2$. Also find the remaining eigenvalue. Determine the natural frequencies of the system in terms of ω.

[7]

(iii) Determine suitable initial conditions for the system in (b) to oscillate in each of its normal modes.

[12]

(c) A uniform solid sphere of mass M and radius a rolls without slipping down a rough plane, inclined at angle β to the horizontal.

Find the linear acceleration of the centre of gravity of the sphere.

[You may assume that the moment of inertia of a solid sphere about a diameter is $\frac{2}{5}Ma^2$

and that counterclockwise moments are positive].

[7]

QUESTION 3

(a) Consider the TPBVP (two point boundary value problem)

$$\frac{d^2G(z)}{dz^2} + \lambda G(z) = 0 \qquad G(0) = 0, \quad G(l) = 0.$$

(i) Prove that the solutions are trivial if $\lambda \leq 0$ but are non-trivial provided

$$\lambda = \frac{n^2\pi^2}{l^2} \qquad n = 1,2,3....$$

(ii) Write down the corresponding eigenfunctions of the TPBVP.

[8]

(b) A steady state solution $u(x,t)$ of the heat equation $u_t = \alpha^2 u_{xx}$ α = constant, is a solution $u(x,t)$ which does not change with time.

(i) Show that all steady state solutions of the heat equation are linear functions of x.

[2]

(ii) Find a steady state solution of the boundary value problem

$$u_t = \alpha^2 u_{xx}$$
$$u(0,t) = T_1$$
$$u(l,t) = T_2,$$

where T_1 and T_2 are constants.

[6]

(c) Using separation of variables $u(x,t) = X(x)T(t)$, show that

$$\frac{\partial u}{\partial t} = \alpha^2 \frac{\partial^2 u}{\partial x^2}$$

can be written as $$\frac{X''}{X} = \frac{\dot{T}}{\alpha^2 T}$$

where λ is a constant. [3]

(d) Solve the heat problem

$$u_t = \alpha^2 u_{xx} \qquad u(x,0) = 135, \quad 0 < x < 1, \qquad u(0,t) = 80 \qquad u(1,t) = 120.$$

[21]

APPM280 : NOVEMBER 1997

QUESTION 1

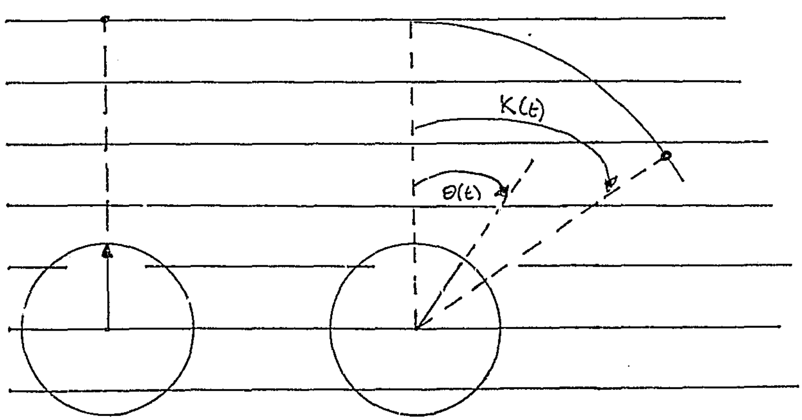
(a) On July 4,1997 a spacecraft named *Pathfinder* landed on Mars, fully equipped with a remotely controlled vehicle called *Sojourner*. The legs of *Pathfinder* remain stationary after landing, but a team of engineers are requested to design a sensor (hereafter called an eye) onboard *Pathfinder*, so that its mechanical eye can continually track the moving *Sojourner* vehicle as it examines the Martian rocks. The engineers develop a sensor, where the movement of the sensor (or mechanical eye) is determined by the second order differential equation :

$$\frac{d^2\theta}{dt^2}+168\frac{d\theta(t)}{dt}+14400\theta=14400K(t)$$

where t = time in seconds

$\theta(t)$ = angular position of the eye at time t

$K(t)$ = position of a moving target which the eye is trying to follow. (See diagram)



(i) Given that the position of the moving vehicle *Sojourner* is described by

$$K(t) = (0.5)(t),$$

fully solve the above second order differential equation for the *Pathfinder* sensor (eye) position $\theta(t)$, subject to the initial conditions below :

INITIAL CONDITIONS: You may assume that at time $t = 0$, the *Pathfinder* mechanical eye is looking straight ahead at its target *Sojourner* and that the *Pathfinder* mechanical eye (sensor) is initially at rest.

NOTE: Your complimentary function must be kept in the form

$$Rf(t)\cos(\alpha t + \beta)$$

where R, f(t), α and β are to be explicitly determined.

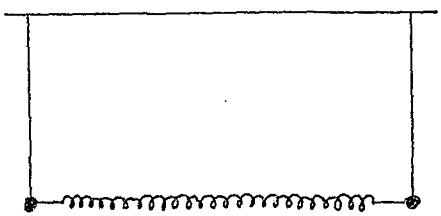
(ii) Distinguish clearly the <u>steady-state</u> and <u>transient</u> parts of your solution in (i).

(iii) What is the period (in seconds) and the number of oscillations per second, of the eye movement $\theta(t)$?

(iv) Draw a graph to compare the position of the eye with the position of the moving target (which the eye is trying to follow) for the time interval $0 \leq t \leq 1$ second.

[30]

(b) Two simple pendulums, each consisting of a mass m suspended by an inextensible string of length L, are connected together by a weightless horizontal spring of stiffness k, as shown.



The system performs *small* horizontal oscillations about its equilibrium position, the displacements of the masses from their equilibrium positions being x_1 and x_2 respectively. For convenience, we define $\omega_1^2 = \frac{g}{L}$ and $\omega_2^2 = \frac{k}{m}$.

Write down (but do NOT solve) the differential equation of motion for each mass and express them, using the definitions of ω_1^2 and ω_2^2, in matrix notation

$$\ddot{X} \equiv \frac{d^2 X}{dt^2} = AX$$

[10]

QUESTION 2

(a) A uniform solid right circular cylinder of mass M and radius a rolls without slipping down a rough plane, inclined at angle β to the horizontal.

Find the linear acceleration of the centre of gravity of the cylinder.

[You may assume that the moment of inertia of the cylinder is $\frac{1}{2}Ma^2$ and that counter clockwise moments are positive].

[8]

(b) Three masses $12m$, $5m$ and $12m$ (in that order) lie in a straight line on a smooth horizontal plane and are connected by four identical horizontal elastic springs each of stiffness k, the end-points being fixed. The system performs (small) longitudinal horizontal oscillations.

Let x_1, x_2 and x_3 (in that order) describe the displacements of these respective masses from their equilibrium positions.

(i) Carefully find a matrix A such that $\ddot{X} = AX$.

Each entry of A should be evaluated in terms of ω, where $\omega^2 = \dfrac{k}{60m}$

[6]

(ii) Determine the natural frequencies of the system in terms of ω.

[7]

(iii) Determine suitable initial conditions for the system in (b) to oscillate in each of its normal modes.

[12]

(c) Consider the vector-matrix differential equation

$$\dot{x}(t) = A(t)\,x(t), \quad x(t_0) = x_0, \qquad x \in \Re^n$$

Find an appropriate matrix differential equation for $V(t)$ such that the integral

$$J = \int_{t_0}^{t_f} x^T(t)Q(t)x(t)dt, \quad Q \in \Re^{nxn}$$

can be written as $J = x_0^T V(t_0) x_0$

[7]

QUESTION 3

(a) Consider the TPBVP (two point boundary value problem)

$$\frac{d^2G(y)}{dy^2} + \lambda G(y) = 0 \qquad G(0) = 0, \quad G(\ell) = 0.$$

(i) Prove that the solutions are trivial if $\lambda \leq 0$ but are non-trivial provided

$$\lambda = \frac{n^2\pi^2}{\ell^2} \qquad n = 1,2,3.....$$

[6]

(ii) Write down the corresponding eigenfunctions of this TVBVP.

[2]

(b) Using separation of variables $u(x,y) = X(x)Y(y)$, show that

$$\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}=0$$

can be written as $$\frac{-X''}{X}=\frac{Y''}{Y}=-\lambda$$ where λ is a constant.

Hence, carefully solve the Dirichlet problem described below :

$$\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}=0$$

For $0 < x < a$, $0 < y < b$, subject to:

$$u(x,0) = 0, \qquad u(x,b) = 0$$
$$u(0,y) = 0, \qquad u(a,y) = 1.$$

[18]

(c) Using your answer determined in (b) above, write down the solution to

$$\nabla^2 u = u_{xx} + u_{yy} = 0$$
$$0 < x < a, \quad 0 < y < b$$

subject to

$$u(x,0) = 0, \qquad u(x,b) = 1$$
$$u(0,y) = 0, \qquad u(a,y) = 1.$$

[6]

(d) A steady state solution $u(x,t)$ of the heat equation

$$u_t = \alpha^2 u_{xx} \qquad \alpha = \text{constant}$$

is a solution $u(x,t)$ which does not change with time.

(i) Show that all steady state solutions of the heat equation are linear functions of x.

[3]

(ii) Find a steady state solution to the boundary value problem

$$u_t = \alpha^2 u_{xx}$$
$$u(0,t) = T_1$$
$$u(\ell,t) = T_2 ,$$

where T_1 and T_2 are constants.

[5]

Appendix 8 : Examples of Analysis

From the June 1994 APPM182 question paper.

Name	Q1(b) [9;6;2;6]	ERROR/S
94/5D	2;2;0;2	concept - R taken as constant in (i) and (ii); comment wrong; concept - R taken as constant.
94/5D1	1;0;0;0	concept - R taken as constant in (i) and (ii); careless in (ii) - signs wrong; comment wrong; concept - tractive effort left out.
94/5D2	2;0;0;0	concept - $P = Fv$ used incorrectly - a assumed constant; comment not to the point; concept - R and $mg\sin\theta$ left out.
94/5D3	0;0;0;-	concept - work-energy relation used
94/5D4	0;0;0;0	concept - formula wrong, R assumed constant; comment not to the point.
94/5D5	1;0;-;-	concept - v and R taken as constant, R not drawn on fbd. No comment. a not found.
94/5D6	2;1;-;0	concept - net force not taken as = 0 in (i) and (ii); no comment; concept - $F = ma = .5mv^2$ used to find a.

Name	Q1(b) [9;6;2;6]	ERROR/S
94/5E	0;0;0;0	concept - used eqns of motion for const acc to find an a in (i); R ignored; comment not to the point; concept - R and mgsinθ ignored.
94/5E1	0;0;0;0	concept - R ignored in (i) and (ii); comment not to the point; concept - R ignored.
94/5E2	2;0;0;0	concept - tractive effort and R taken as constant in (i) and (ii); comment not to the point; concept - tractive effort and R taken as constant.
94/5E3	4;0;0;0	careless - formula incorrect, and concept - R taken as constant in (i) and (ii); Comment not to the point;concept - R taken as constant.
94/5E4	0;0;-;-	concept - energy formulas used.
94/5E5	2;0;-;2	concept - tractive effort taken as constant and $a \neq 0$; - ; concept - tractive effort taken as constant
94/5E6	0;-;0;0	concept - energy concepts used; -; comment not to the point; concept - tractive effort taken as constant, R ignored.

From the November 1996 APPM280 examination

	Q1e [10]	Error/s
95/6A	3	careless, concept
95/6A1	5	incomplete
95/6A2	2	concept
95/6A3	4	concept
95/6A4	4	careless
95/6A5	5	careless
95/6A6	2	concept

	Q1e [10]	Error/s
95/6C	0	concept, incomplete
95/6C1	2	concept, incomplete
95/6C2	0	concept, incomplete
95/6C3	--	
95/6C4	3	incomplete
95/6C5	7	careless

APPM280 : NOVEMBER 1996 : ERROR ANALYSIS

	Q1a	Q1b	Q1c(i)	Q1c(ii)	Q1c(iii)	Q1d	Q1e	Q2a	Q2b(i)	Q2b(ii)	Q2b(iii)	Q2c	Q3a	Q3b	Q3c	Q3d
95/6A				concept	------	careless	concept			careless	careless	concept				
95/6A1			concept	concept	------	careless	incomp			incomp	careless	careless				
95/6A2				careless	-------	careless	concept				careless		careless			careless
95/6A3						incomp	concept			incomp	careless	careless				
95/6A4	concept			concept	concept	careless	careless	careless			careless					careless
95/6A5						careless	careless		careless	careless	incomp	careless	careless			careless
95/6A6					careless	careless	concept		careless	careless						careless

	Correct	careless	incomplete	concept	omitted
95/6A	9	3	0	3	1
95/6A1	8	3	2	2	1
95/6A2	9	5	0	1	1
95/6A3	11	2	2	1	0
95/6A4	8	5	0	3	0
95/6A5	8	7	1	0	0
95/6A6	10	5	0	1	0

Averages for Bookwork and Applications Questions.

APPM182	Bookwork	Applications
College	15.6	40.2
Main Stream	15.7	39.9

APPM280	Bookwork	Applications
College	18.7	46.4
Main Stream	20.9	46.56

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